Missouri Department of Natural Resources
Water Protection Program

Total Maximum Daily Loads (TMDLs)

for

Center and Turkey Creeks
Jasper County, Missouri

Completed: September 22, 2006
Approved:

Total Maximum Daily Loads (TMDLs)
For Center and Turkey Creeks
Pollutant: Zinc

Name: Center Creek

Location: North of Joplin in Jasper County, Missouri

Hydrologic Unit Code (HUC): 11070207

Waterbody Identification Number (WBID): 3203

Missouri Stream Class: Class P[1]

Beneficial Uses:
Livestock and Wildlife Watering
Protection of Warm Water Aquatic Life
Protection of Human Health associated with Fish Consumption
Cool Water Fishery
Whole Body Contact Recreation – Category A
Secondary Contact Recreation
Irrigation
Industrial

Size of Impaired Segment: 11 miles

Location of Impaired Segment: From W 1/2, Section 5, T28N, R32W (upstream) to W1/2, Section 14, T28N, R34W (downstream)

Pollutant: Zinc

Pollutant Source: Tri-State Abandoned Mine Lands

TMDL Priority Ranking: Medium

Name: Turkey Creek

Location: Near Joplin in Jasper County, Missouri

Hydrologic Unit Code (HUC): 11070207

Waterbody Identification Numbers: 3216, 3217

[1] Class P streams maintain flow even during drought conditions. See 10 CSR 20-7.031(1)(F).

Missouri Stream Class: Class P

Beneficial Uses:
WBID 3216
Livestock and Wildlife Watering
Protection of Warm Water Aquatic Life
Protection of Human Health associated with Fish Consumption

WBID 3217
Livestock and Wildlife Watering
Protection of Warm Water Aquatic Life
Protection of Human Health associated with Fish Consumption
Whole Body Contact Recreation – Category A

Size of Impaired Segment:
WBID 3216 -- 5 miles and WBID 3217 -- 3.5 miles

Location of Impaired Segments:
WBID 3216: From Section 35, T28N, R33W (upstream) to Section 29, T28N, R33W
WBID 3217: From Section 9, T27N, R32W (upstream) to Section 35, T28N, R33W

Pollutant: Zinc

Pollutant Sources:
WBID 3216 – Multiple Lead and Zinc Abandoned Mine Lands
WBID 3217 – Duenweg Abandoned Mine Lands

TMDL Priority Ranking: Medium

1.0 Background and Water Quality Problems

1.1 Physical Characteristics (Including Land Use)

The Spring River Basin, including Center and Turkey Creeks, is located in southwest Missouri in the Springfield Plateau physiographic region. Center and Turkey Creeks are typical Ozark streams characterized by alternating pools and riffles, with mixed sand, gravel and boulder bottoms. The climate of the Spring River Basin is continental, with moderate winters and long, warm summers. Rainfall totals about 40 inches per year and the region receives about 12-16 inches of snow each year. One third of the year's rainfall and 60 percent of flooding occurs during the months of April, May and June. About 25 percent of the annual precipitation is available to stream flow and ground water recharge, with the balance lost to evapotranspiration.[2] The prevailing winds are from the south and are generally most active in the spring. The growing season averages about 200 days per year.[3]

[2] Water-Quality Characterization of the Spring River Basin, Southwestern Missouri and Southeastern Kansas, U.S. Geological Survey, Water-Resources Investigations Report 90-4176, 1992 pg. 6.
[3] Water Quality: James, Elk Spring River Basins, Missouri Clean Water Commission, 1973, pg. 32.

Data from 2000 (30-meter resolution) obtained from Thematic Mapper imagery was used to calculate landuse statistics for both watersheds (see maps in Appendix A). Land use in the Center Creek Basin (see Appendix A-1) consists of a mixture of row crop, pasture, forested land and mined land. Erosion has been estimated to total about 2.5-5.0 tons per acre per year and gully erosion at 0.15-0.3 tons per acre per year, which are considered to be low to moderate and not considered to be a large problem. Turkey Creek (Appendix A-2), which drains the northern portion of the City of Joplin, is approximately 67 percent crop and pastureland, 14 percent forested land and 17 percent urban land. Three percent is open water. Sheet erosion is rated at 2.5 to 5.0 tons per acre per year and gully erosion at 0.15 to 0.3 tons per acre per year, considered to be low to moderate, and like Center Creek, not considered to be a large problem.[4]

Center Creek begins north of Monett, Missouri, and flows westward across Lawrence County, through the northeastern corner of Newton County, and across Jasper County to meet the Spring River at the Kansas/Missouri state line. Center Creek is about 60 miles long and its watershed is comprised of 302 square miles. The creek drains approximately 93 percent of the lead-zinc mined area of the watershed, principally from the Oronogo-Duenweg mining region. At one time, over 2,000 acres of tailings piles were found along Center Creek. At least three flowing mines are reported to discharge into the creek. According to one report, during the 1930s, drainage ditches were constructed by the Works Progress Administration to collect rainwater and convey it away from mine openings to prevent mine flooding. These drainage ditches at the time of the report still functioned and continued to discharge zinc-bearing rainwater into Center Creek[5], and they still do today. Eleven miles of Center Creek are on the 303(d) list for zinc contamination from Tri-State Abandoned Mine Lands (AMLs).

Turkey Creek originates in northwestern Newton County, flows northwesterly across the southwest corner of Jasper County, and enters the Spring River about one-half mile inside the State of Kansas. Turkey Creek is approximately 18 miles long and has a drainage area of about 48 square miles including the north edge of the City of Joplin. Turkey Creek drains approximately 18 percent of the lead-zinc mine land in the Joplin area. Eight and one-half miles of the creek are on the 303(d) list for zinc contamination from several AMLs, including Duenweg. Point sources on Turkey Creek include the Joplin/Turkey Creek Wastewater Treatment Facility (WWTF) and an asphalt products manufacturing plant.

1.2 Geological Characteristics of Basin

The Center and Turkey Creek area is underlain with Mississippian limestone, the oldest rocks in the state, which formed about 354 million to 323 million years ago. Zinc is commonly found in water issuing from Mississippian limestone.[6] Zinc is an essential nutrient to aquatic and terrestrial organisms but in excess can be highly toxic. It tends to bioaccumulate in the environment and can produce certain behavioral and physiological effects in test organisms exposed to high levels. For instance, behavioral responses to zinc in fish include avoidance and changes in feeding rate and movement patterns. Physiological changes in fish include increased ventilation rates, frequency of coughing and a decrease in oxygen utilization.[7]

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[4] Missouri Department of Natural Resources Basin Plans, Basins 74 and 75

[5] Water Resources of the Joplin Area, Mo., Feder, G.L., et al, Missouri Geological Survey & Water Resources, 1969 pg. 6-8.

[6] Water Resources of the Joplin Area, Mo., Feder, G.L., et al, Missouri Geological Survey & Water Resources, 1969 pg. 16.

[7] Red Clay Creek TMDL, Delaware Natural Resources and Environmental Control, 8/1/99. www.dnrec.state.de.us/DNREC2000/Library/Water/rcctmdl.pdf

Major minerals in the basin include: galena (PbS), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), pyrite/marcasite (FeS_2), calcite ($CaCO_3$), dolomite ($Ca,Mg(CO_3)_2$) and quartz (SiO_2). Galena and sphalerite are commercially important and are the minerals from which lead and zinc are derived. These two minerals are found in association and are mined together.

Sphalerite (zinc sulfide) is also known as "zinc blende". Miners found sphalerite difficult to distinguish from more valuable minerals like galena. The name "sphalerite" is Greek for "treacherous rock" and "blende" is German for "deceiving"[8]. Cadmium is also found in sphalerite and can affect water quality when released from rocks by rainfall runoff.

Pyrite is another important mineral involved in acid mine drainage. The name "pyrite" comes from the Greek word pyr, "fire," because pyrite emits sparks when struck by steel. This phenomenon was utilized for the wheel-lock gun, an early type of firearm. Pyrite does not dissolve and does not react readily with oxygen; however, under the right conditions, it can form acid drainage. Following a complex series of reactions with the right pH and in the presence of air and water, solubilization occurs and acid drainage is created. The reactions of solubilization can be expressed in the following equations located in 1.3 Chemical Characteristics of the Basin, which follows. The actual steps are many times greater in number.

Chert, also known as flint or jasper, is a fine-grained, non-crystalline sedimentary rock made up of silicon dioxide (SiO_2). Chert layers are commonly found in western Missouri, occurring as irregular beds or rounded nodules within limestone formations. Chert is harder than limestone and tends to remain after the limestone is weathered away.

Mineral deposits usually exist in areas where chert is mixed with angular fragments of rocks cemented with other kinds of rocks, called breccia. This breccia is highly permeable by rainwater and is surrounded by impermeable limestone, known locally to miners as "lime bars". The slightly acidic rainwater dissolves the limestone holding the breccia together, causing collapse similar to formation of sinkholes in karst topography. One report characterized this kind of solution formation as different from karst because it is associated with more ancient rock formations than karst. However, it behaves similarly and forms cave-like or sinkhole-like structures, which causes collapses characterized by loose collections of rock. Minerals found in the water percolating through the breccia become attached to the chert. Erosion or water table changes make the minerals available for oxidation and contribute to the naturally high zinc levels in water in the area.

Four types of zinc and lead deposits are found in the Joplin area and are important in understanding the history and mining process in southwest Missouri. These include upper-ground, middle-ground, sheet-ground and Reed Springs deposits.

- Upper-ground deposits are found at the surface and can extend to 100 feet in depth. The minerals are found in erratic masses in brecciated chert and limestone, mixed with other kinds of rocks. The minerals were easily found and mined using open pit and shallow underground mining methods.
- Middle-ground deposits are found between 100 and 175 feet below the surface. These are mostly breccias moderately cemented and are considered similar to upper-ground ores.

[8] http://mineral.galleries.com/minerals/sulfides/sphaleri/sphaleri.htm.

- Sheet-ground deposits were extensively mined mineral deposits and occur as sheets found between fractured chert. These deposits were mined using very large room and pillar underground mining methods. This resulted in large quantities of mining waste and lower grade ores than the upper-ground deposits.
- Reeds Springs deposits were irregular and located beneath the sheet-ground depth making them hard to find, but were relatively high grade. Fine particles made this deposit difficult to mill. Few of these deposits were ever discovered and exploited.[9]

This area is known as the Tri-State Historic Mining District because it includes southwest Missouri, southeast Kansas, and northeast Oklahoma. From the 1850s to the 1960s, the district was the highest producing lead and zinc mining area in the world. According to one study, the ore was characterized as extremely low grade and found in hard rock that was difficult to mill and mine. This study attributed the success of the district to cheap power and labor, low capital investment and proximity to the markets. The companies were able to make a profit on as little as $0.50 to $1.00 per ton of mined and milled ore.[10]

1.3 Chemical Characteristics in Basin

The oxidation of a common mineral in the basin, pyrite (FeS_2), is responsible for the formation of acid-rock drainage. Oxidation of pyrite produces dissolved sulfate, ferrous iron and acidity. Ferrous iron oxidizes to form ferric iron and more acidity. This is practically a self-perpetuating cycle that produces more and more acid. As long as the pyrite is encased underground, it is unavailable and does not produce acid. Once oxygen or oxygenated water comes in contact with the minerals through mining activity causing fresh rock surfaces, mining shafts conducting surface oxygen into the mines, or rainwater entering shafts, oxidation can occur. The process is denoted chemically as follows:

$$FeS_2(s) + 15/4\ O_2 + 7/2\ H_2O \rightarrow Fe(OH)_3(s) + 2\ SO_4^{2-} + 4H^+$$

The oxidation of another common mineral, sphalerite, follows from this chemical reaction. Sphalerite can be dissolved by the acidic solutions from the oxidation of pyrite, in this case sulfuric acid. Its reaction is as follows:

$$ZnS + 2H^+ \rightarrow Zn^{2+} + H_2S$$

Abandoned mines eventually become filled with either groundwater or rainwater. Oxygenated water reacts with minerals present in the mine to form acid mine drainage. The acidified water flows out of fissures or from the mine entrance and enters the surface water system. Aquatic life cannot survive in the presence of low pH, resulting in streams devoid of life. Limestone, which has a high pH in some of the mines, neutralizes the acidified water, rendering the water less damaging to stream systems.

[9] Draft Remedial Investigation Neck/Alba, Snap, Oronogo/Duenweg, Joplin, Thoms, Carl Junction, and Waco Designated Areas, Jasper County Site, Jasper County, Missouri, Dames & Moore, 1994.
[10] Water Resources Contamination from Abandoned Zinc-Lead Mining-Milling Operations and Abatement Alternatives, Ozark Gateway Council of Governments, 1980 pg 4.

1.4 Hydrologic Characteristics in Basin

Two important aquifers in the area are the shallow aquifer found in cherty limestone and the deep aquifer found in cherty dolomite and sandstone. This shallow aquifer extends from the surface to about 400 feet below ground. The deep aquifer goes to about 2,000 feet below the surface. A relatively impermeable layer of silty limestone and shale separates the aquifers. The deep aquifer is under slight artesian pressure.

The Joplin area has individual underground water zones called "pools" surrounded by impermeable limestone (lime bars) that range from small isolated water pockets to large pools that can cover hundreds of square miles. Because of the impermeable limestone surrounding them, the pools are trapped in these pockets with little lateral movement to adjoining pools. This enabled miners to pump water out of the mines without affecting neighboring pools. Once mining operations expanded and tunnels merged, individual pools became connected and mine drainage became a larger problem. Drainage cooperatives were established to share expenses and to try to get ahead of the rising water. By 1934, eight pools in the Duenweg-Oronogo area had been connected. Mine pumping studies at that time determined the entire 14 square mile area could be drained in six months by using 17 pumping stations with pumping capacity of 5,000 to 6,000 gallons per minute (gpm) to keep the mines from flooding again. This figure was only accurate if provisions were made to keep surface water from entering mineshafts. An older study from 1919 calculated that pumping capacity would have to be able to handle as high as 13,000 gpm, depending on the season.[11]

Karst features in this region include caves and springs, but few sinkholes except subsidence pits from mining. Springs in the area are supplied by the shallow aquifer. For this reason, it is likely that they are contaminated by metals, though no studies or source tracing has been conducted. Water yields tend to be small and are influenced by area rainfall.

Table 1: Springs located in the Center Creek watershed

Name of Spring	County	Flow in cubic feet per second (cfs)
Button	Newton	3.5
Clarkson	Lawrence	10.4
Ell Lynn	Newton	0.86
Haddock	Newton	6
Mossy	Jasper	3
Radar Station	Jasper	0.3
Scotland	Jasper	3.08
Sonnywood	Jasper	0.55

Clarkson Spring in Lawrence County is at the headwaters of Center Creek and is responsible for much of the baseflow for the creek.

[11] Water Resources Contamination from Abandoned Zinc-Lead Mining-Milling Operations and Abatement Alternatives, Ozark Gateway Council of Governments, 1980 pg 15.

Turkey Creek has one reported spring in its basin. Great Western Spring is located in Jasper County and has a flow of 0.3 cubic feet per second.[12]

1.5 Basin Water Quality Studies

A variety of studies have been conducted over the years to determine various water quality problems on both Center Creek and Turkey Creek. All of these studies have noted that upper Center Creek water quality is good, but that water quality deteriorates once Grove Creek joins Center Creek. A Missouri Department of Conservation study conducted in 1976 reported that lower Center Creek and Turkey Creek had invertebrate communities indicative of polluted streams. In fact, Turkey Creek has been called Missouri's most polluted interstate stream.[13] Some of these studies examined parameters other than zinc contamination, but they provide a wealth of information on the history and problems that exist in the Joplin abandoned mine land region. A partial list of known studies from 1958 to 1997 may be found in the addendum.

1.6 History of the Basin Area

The territory that became Jasper County was originally part of the homeland of the Osage Indians. In 1808, the land was bought for $1,200 cash and $1,500 in trade goods. The tribe was moved across the border into what was then "Indian Territory", yet groups of Osage freely moved through the area for years thereafter. In 1825, another treaty completed the takeover of Osage land and they were forced to leave the state. The Osage or Sarcoxie War occurred in the Summer of 1837 when a number of Osage Indians encamped near Sarcoxie were accused of stealing horses. Militia from Springfield rode out to meet the party, who were in their traditional homeland on a hunting and fishing expedition. The hunting party and militia met for a council and the Native Americans were compelled to promise they would go back to their reservation and never cross the border again. Later it was proved that the Osage had not stolen any property and that the panic had been for nothing. No lives were lost, but the Sarcoxie War ended the presence of the Osage Indians in southwest Missouri.

Jasper County was created by an act of the Missouri legislature on January 29, 1841 and named for Sergeant William Jasper, a Revolutionary War hero. Center Creek was the homesite of the first white settler in the county in 1931 and a mill was built on the creek in 1839. The first lead furnace in Jasper County was established on Center Creek (spelled Centre Creek in the old histories) at French Point in 1849 or 1850. The lead used there was mined on Turkey Creek.

The local population was about evenly split in sentiments during the Civil War. Control of the county changed constantly between Union and Confederate forces during that time. The county records were moved for safety from Carthage to Neosho and from there to Fort Scott, Kansas, a Union stronghold. With so much troop movement, there were many opportunities for skirmishes and battles, resulting in destruction of property, including the burning of the towns of Sarcoxie, Neosho and Carthage.

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[12] Springs of Missouri, Missouri Department of Natural Resources, Division of Geology and Land Survey, Howe, W.B. pg. 159-166.

[13] Water-Quality Characterization of the Spring River Basin, Southwestern Missouri and Southeastern Kansas, U.S. Geological Survey, Water-Resources Investigations Report 90-4176, 1992 pg. 13

One of the first battles of the Civil War occurred on July 5, 1861 near Carthage. The Battle of Carthage began when 1,100 Union soldiers under the command of Colonel Franz Siegel sent from St. Louis to southwestern Missouri encountered the 6,000 Rebel troops under the command of General Sterling Price. The better trained and armed Federal troops prevailed initially, but the Rebel forces began to overwhelm them by sheer force of numbers. General Siegel's troops retreated toward Sarcoxie and escaped capture. The victory at Carthage provided the Rebel troops with battle experience and a much-needed victory, plus enabled them to work the lead mines of the area for ammunition without harassment from Union forces. The battle site is now a Missouri state park.

1.7 Mining in the Basin Area

The discovery of lead in southwest Missouri in 1848 began the mining boom in the Joplin area, which lasted until 1957. The Joplin area is part of one of the richest zinc-lead ore deposits in the world and covers approximately 25,00 square miles, known as the Tri-State Historic Mining District. Between 1848 and 1945, 50 percent of the zinc and 10 percent of the lead mined worldwide came from the Tri-State district. The Oronogo lead deposit was first mined in 1852. The town established there became the largest lead shipping station in the world. A solid lead chunk found at Oronogo yielded 30,000 pounds of lead. The District produced about 460 million tons of lead and zinc ore at an estimated value of $2.1 billion. Missouri produced about 40 percent of that total during the mining years of about 1848 to 1957. Mining in the District ended in 1970 when the last active mine, located two miles west of Baxter Springs, Kansas, closed due to environmental and economic problems.

During and after the mining period, tailings were marketed whenever possible. Remilling of better grade piles of zinc and lead tailings continued until about the 1950s when that supply ran out. Lower grade tailings consist of chert, limestone, dolomite, shale and minerals. Larger size pieces, "chats" are used for railroad ballast, roadbed material, asphalt ingredients and concrete aggregate. Small pieces, sands and slimes, are used for roofing granules and industrial abrasive materials. Boulders are used for fill material and riprap. Of the large piles of mine waste, approximately 80 percent has been sold and removed. In 1977, it was estimated that about 54 million tons of mine waste was still available, mostly located in small, isolated piles.[14] When the area was made an EPA Superfund site, it was estimated that 9 million tons of mining/milling and smelter wastes containing residual metals, particularly lead, cadmium and zinc, remained.

1.8 Defining the problem:

Mine drainage, both in the form of surface flows and resurgence of groundwater from flooded mines, contributes significant amounts of zinc to Center and Turkey creeks. Both of the creeks are major contributors of metals pollution to the Spring River in Kansas. Kansas has already written a TMDL for the Spring River, which clearly shows the negative impact of the Missouri streams on that waterbody.

Upstream of the mining district on Center Creek (near Fidelity), the average dissolved zinc concentration is 7 µg/L. At the Highway HH bridge, which is just within the upstream portion of the mining district, it is 124 µg/L and rises to 366 µg/L well within the mining area at Smithfield.

[14] Water Resources Contamination from Abandoned Zinc-Lead Mining-Milling Operations and Abatement Alternatives, Ozark Gateway Council of Governments, 1980. pgs.13 and 14.

Studies by the U.S. Geological Survey also indicated that pore water (water within the sediment on the bottom of Center Creek) at some locations was toxic to aquatic life. The results of these toxicity tests correlated with amounts of zinc in the stream sediments and thus zinc is believed to be the toxic agent.

Two segments of Turkey Creek are on the 303(d) list for high levels of zinc. Several AMLs provide zinc to Turkey Creek, with the Duenweg mining area being the most significant contributor in the upper Turkey Creek watershed. In the middle portion of the watershed, the Lone Elm Hollow and Leadville Hollow areas are the most significant sources. Zinc levels frequently exceed state water quality standards during low flow periods.

Most of the zinc in these two creeks comes from dissolution of zinc minerals lying on the land surface or in the walls of flooded mines. As these surfaces continue to weather, or are buried through remediation efforts, less available zinc remains to be dissolved and the long-term levels of zinc in runoff, groundwater and in the two creeks should decline. For maps of the area and the accompanying data, see Appendices B and D.

2.0 DESCRIPTION OF THE APPLICABLE WATER QUALITY STANDARDS AND NUMERIC WATER QUALITY TARGETS

2.1 Beneficial or Designated Uses

These uses are listed on pages one and two. The use that is impaired in both creeks is protection of warm water aquatic life.

2.2 Anti-degradation Policy

Missouri's Water Quality Standards (WQS) include the U.S. Environmental Protection Agency (EPA) "three-tiered" approach to anti-degradation, which may be found at 10 CSR 20-7.031(2).

Tier 1 – Protects existing uses and provides the absolute floor of water quality for all waters of the United States. Existing instream water uses are those uses that were attained on or after Nov. 29, 1975, the date of EPA's first WQS Regulation, or uses for which existing water quality is suitable unless prevented by physical problems such as substrate or flow.

Tier 2 – Protects the level of water quality necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water in waters that are currently of higher quality than required to support these uses. Before water quality in Tier 2 waters can be lowered, there must be an antidegradation review consisting of: (1) a finding that it is necessary to accommodate important economical or social development in the area where the waters are located; (2) full satisfaction of all intergovernmental coordination and public participation provisions; and (3) assurance that the highest statutory and regulatory requirements for point sources and best management practices for nonpoint sources are achieved. Furthermore, water quality may not be lowered to less than the level necessary to fully protect the "fishable/swimmable" uses and other existing uses.

Tier 3 – Protects the quality of outstanding national resources, such as waters of national and state parks, wildlife refuges and waters of exceptional recreational or ecological significance. There may be no new or increased discharges to these waters and no new or increased discharges to tributaries of these waters that would result in lower water quality (with the exception of some limited activities that result in temporary and short-term changes in water quality).

2.3 Missouri's Specific Criteria

Missouri's WQS, 10 CSR 20-7.031, have recently been revised to include new metals criteria. WQS Section (4)(B)(1) and (2) outline the method by which zinc is presently analyzed. The standards themselves may be found in Table A - Criteria for Designated Uses. This gives the maximum amount in µg/L (micrograms per liter[15]) as dissolved metal of various metals (other than mercury) for each designated use. The new criteria determination is based on EPA's guidance (EPA820B96001). For the protection of aquatic life and human health associated with fish consumption, the formulas for zinc criteria are shown below:

Acute: $e^{(0.8473*\ln(\text{Hardness}) + 0.884211)} * 0.978 = \mu g/L$ of Dissolved Zinc

Chronic: $e^{(0.8473*\ln(\text{Hardness}) + 0.785271)} * 0.986 = \mu g/L$ of Dissolved Zinc

General Formula: Dissolved = Total Recoverable * Conversion Factor

Where "e" is the base of the natural logarithm (also called exponential and symbolized by EXP), "ln" is the natural logarithm. Both 0.986 and 0.978 are conversion factors that are used to convert criteria between total and dissolved forms. From this mathematical relation, it is apparent that the zinc concentration is positively related to hardness. As water hardness increases, so does the criterion. It follows that hardness mitigates the toxicity level of dissolved zinc on aquatic life (EPA-440/5-87-003). It is also apparent that for any given hardness value, acute criteria are 1.095 times greater than chronic criteria. Consequently, protecting aquatic life at the chronic level will certainly protect them at the acute level. The data show that there is no significant relation between zinc concentration (dissolved or total) and stream flow. For instance, flow and dissolved zinc concentration in the Center Creek watershed have a correlation coefficient of - 0.099.

2.4 Neighbor State Considerations and the Numeric Water Quality Target

The Spring River watershed extends into Kansas and Oklahoma, which in terms of water flow direction, are downstream of Missouri. It is standard procedure for the upstream state of a shared water body (Missouri, in this case) to have to meet the standards of the downstream state(s), if those standards are more stringent. Therefore, the TMDL zinc target may not violate the WQS of either Kansas or Oklahoma. Also, Kansas has already written a TMDL for the Spring River using their metals standards as the end point. Kansas and Missouri use basically the same formula to calculate zinc criteria; however, there are some differences. While Kansas uses <u>total recoverable</u> zinc to protect for drinking water supply use of the Spring River, Missouri uses <u>dissolved</u> zinc to protect aquatic life. To protect downstream uses, in addition to a dissolved zinc target, a total zinc criterion and corresponding TMDL will be determined. These will be based on the formula in Kansas' WQS, which is:

Acute or Chronic = WER[EXP[(0.8473*(ln(hardness)))+0.884]] = µg /L total zinc.

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[15] 1 microgram = 10^{-6} gram. One µg/L is equivalent to 1 part-per-billion (1 ppb).

The water effect ratio equals one (1) and EXP equals exponential (as “e” in Missouri’s formula). For more information, please refer to the Kansas Department of Health and the Environment’s Web site at: www.kdhe.state.ks.us/water/download/kwqs_plus_supporting.pdf

The Spring River flows through Kansas for over 15 miles before entering Oklahoma. The mouth of the Spring River is in the territory of Oklahoma’s Quapaw[16] Tribe. This tribe adopted federal zinc criteria, which is the same as Missouri’s. Therefore, Missouri’s TMDLs will be protective of the tribe’s water quality as related to zinc, all that is required for Missouri is to meet Kansas’ zinc standard at the Missouri/Kansas state line.

3.0 LOADING CAPACITY

Loading capacity is defined as the maximum pollutant load that a waterbody can assimilate and still attain WQS. Loading capacity is the sum of the Wasteload Allocation (WLA), Load Allocation (LA) and Margin of Safety (MOS).

3.1 Modeling Approach

The modeling approach for these TMDLs consisted of creating a Load Duration Curve for the outlet of the impaired segments’ watershed and determining the TMDL at every flow probability. A TMDL is the product of the standard of concern (in mg/L), the expected flow at the corresponding probability (in cubic feet per second, ft^3/s), and a conversion factor (5.395). The resulting target load is expressed in pounds per day. The existing (observed) load of zinc is then plotted against the TMDL curve based on the probability of its corresponding flow (Figure 1 is the first example). Where flow was not reported with the water quality data, estimated average daily flow at the site on the same date was used to calculate the zinc load. A similar procedure was employed to estimate hardness for Center Creek for the observed zinc data. Missing hardness values were looked up from the flow-hardness relationship. Because the zinc standard is hardness dependent, and zinc load increases with flow, the TMDL is expressed in probability flow at a specific hardness. The load reduction is expressed in percentage of existing loads within selected flow probability ranges. The target load for each flow range is that load which corresponds to the flow at the mid-point of the range. A representative statistic – in this case the 95th percentile - of all observed loads within the same flow range is compared to the target load. The 95th percentile is more conservative than the arithmetic average because it yields a higher reduction.

4.0 CENTER CREEK

Center Creek was divided into two sub-watersheds to compare data for impaired and non-impaired segments of the stream: Carterville upstream with about 148,480 acres and Smithfield with about 192,000 acres. There are U.S. Geological Survey gauging stations at the outlet of each of these two sub-watersheds; however, only the Carterville station recorded average daily flows. The Carterville station is at site E2/G5 on the map in Appendix B-1. The Smithfield station is at site E13/G14.

4.0.1 Carterville Sub-Watershed

A site near Carterville (USGS site 7186400 at Highway HH 1.5 miles below Grove Creek) was used as the outlet for this sub-watershed. The gauging station at this site operated from June 1, 1962

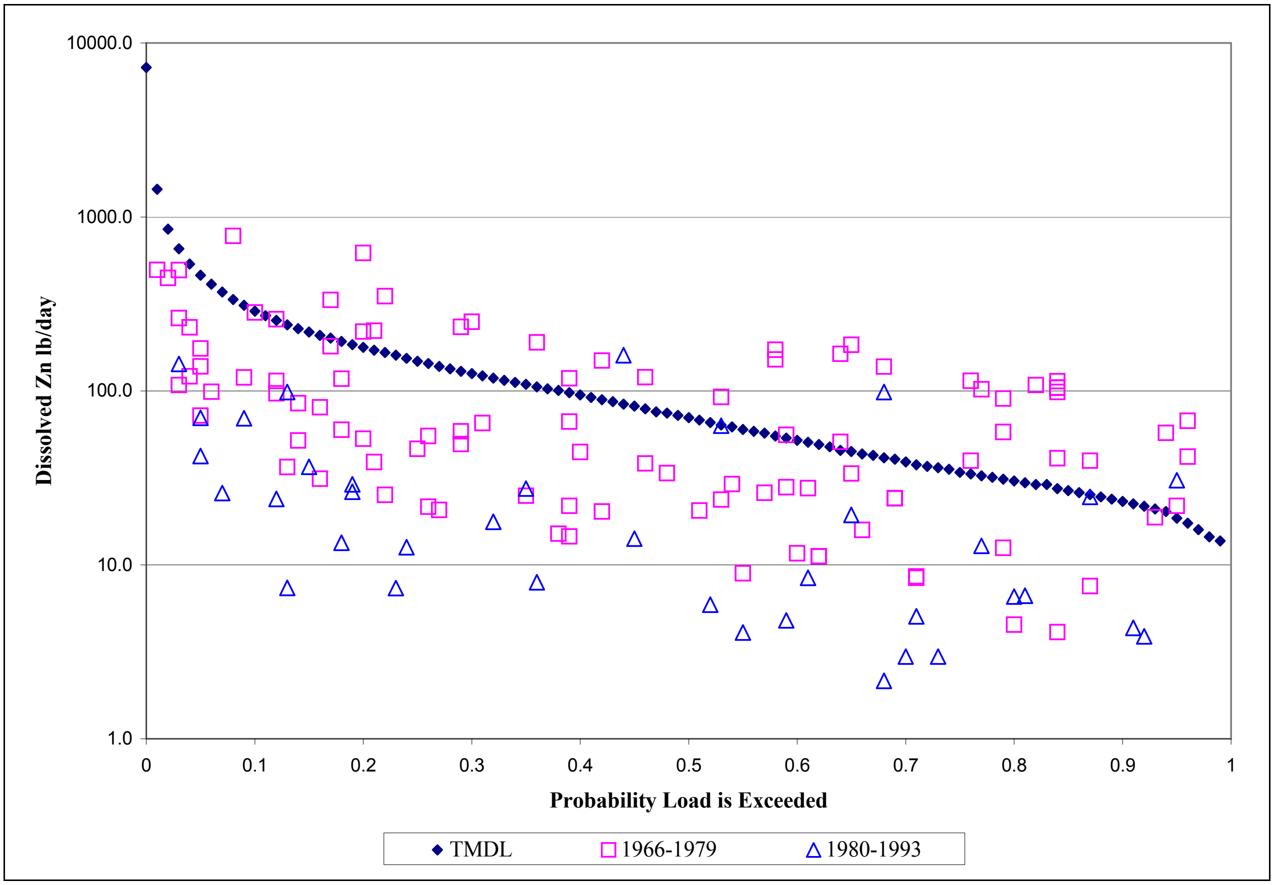
[16] epa.gov/waterscience/tribes/regs.htm

until September 30, 1991, with 10,713 daily flow records. There are 145 dissolved zinc records (1966-1993), 40 total zinc records (1976-89) and 121 hardness records (1966 to 1993). This data can be found in Appendix D-1 with a graph of the hardness in Appendix C-1. Sixty-seven percent of the hardness data values at the Carterville site are less than or equal to 150 mg/L, with an average of 149, a standard deviation of 32, and a 25th percentile of 130 mg/L[17]. The chronic dissolved zinc criterion at this site corresponding to a hardness of 130 mg/L is 134 µg/L and the corresponding Kansas's total zinc criterion is 136 µg/L (chronic or acute).

The existing load of dissolved zinc is plotted against the TMDL curve based on the probability of its corresponding flow (Figure 1). The dissolved zinc load, as weighted by stream flow regime, has seen a significant decrease over time in this sub-watershed. Figure 1 depicts such a decrease from 1966 through 1993. This graph shows that the observed dissolved zinc loads measured at this site exhibited a steady reduction of exceedence from 36 percent in the period of 1966-1979 to 18 percent during the period from 1980-1993. Actual total zinc data collected at this site exceeded Kansas's current criteria 20 percent of the time. It should be noted however, that the impaired stream segment is downstream of this sub-watershed and the current standards are more stringent than the previous ones. These zinc data values were deemed as meeting water quality standards when compared to the 1996 zinc criteria used when the stream was first listed.

[17] From Missouri's Water Quality Standards 10 CSR 20-7.031 (1) (Y): Water hardness—The total concentration of calcium and magnesium ions expressed as calcium carbonate ($CaCO_3$). For purposes of this rule, hardness will be determined by the lower twenty-fifth percentile value of a representative number of samples from the water body in question or from a similar water body at the appropriate stream flow conditions.

Figure 1: Daily Load of Dissolved Zinc from Carterville Sub-Watershed



The TMDL curve sets the maximum load at different flow probabilities. In a stream that is not impaired, all observed data points should fall on or below this curve. In general, any excursions at probabilities greater than that of baseflow are caused by point sources (and ground seepage in the case of abandoned mine lands).

4.0.2 Smithfield (or Center Creek) Watershed

This site (USGS 07186480 at Center Creek near Smithfield) is about one mile from the mouth of Center Creek. For the purpose of this calculation, this site will serve to evaluate dissolved zinc loading from the whole Center Creek watershed. Since this station did not gather flow data, the average daily flow of Center Creek at Smithfield was synthesized from that of Carterville (USGS 07186400) based on their watershed area ratio. There are 379 hardness records in the whole Center Creek watershed, including 235 at this site (Appendices C-2 and D-2). Hardness mean (average), standard deviation, and 25th percentile for the whole watershed are 176, 59, and 147 mg/L respectively. Compare this to the Smithfield site alone that had 184, 35, 160 mg/L respectively. The TMDL calculation used a hardness of 147 mg/L (25th percentile for the whole watershed) to derive the target zinc concentrations.

Using the new water quality formula (Section 2.3 Specific Criteria) and a hardness of 147 mg/L, zinc TMDL targets for Center Creek watershed are:

- **Missouri's chronic criterion is 148 µg/L as dissolved, and**
- **Kansas's acute and chronic criteria are 150 µg/L as total.**

From 1993-2003, observed dissolved zinc data exceeded the TMDL 50 percent of the time (Figure 2). During that same time period, total zinc load exceeded the TMDL 92 percent of the time (Figure 3). Since total zinc load requires a larger reduction than dissolved zinc to achieve WQS in Center Creek, this TMDL will target total zinc. Any reduction in total zinc will encompass a reduction in dissolved zinc.

Figure 2: Center Creek Daily Load of Dissolved Zinc Measured at USGS 07186480 near Smithfield in Jasper County, Missouri

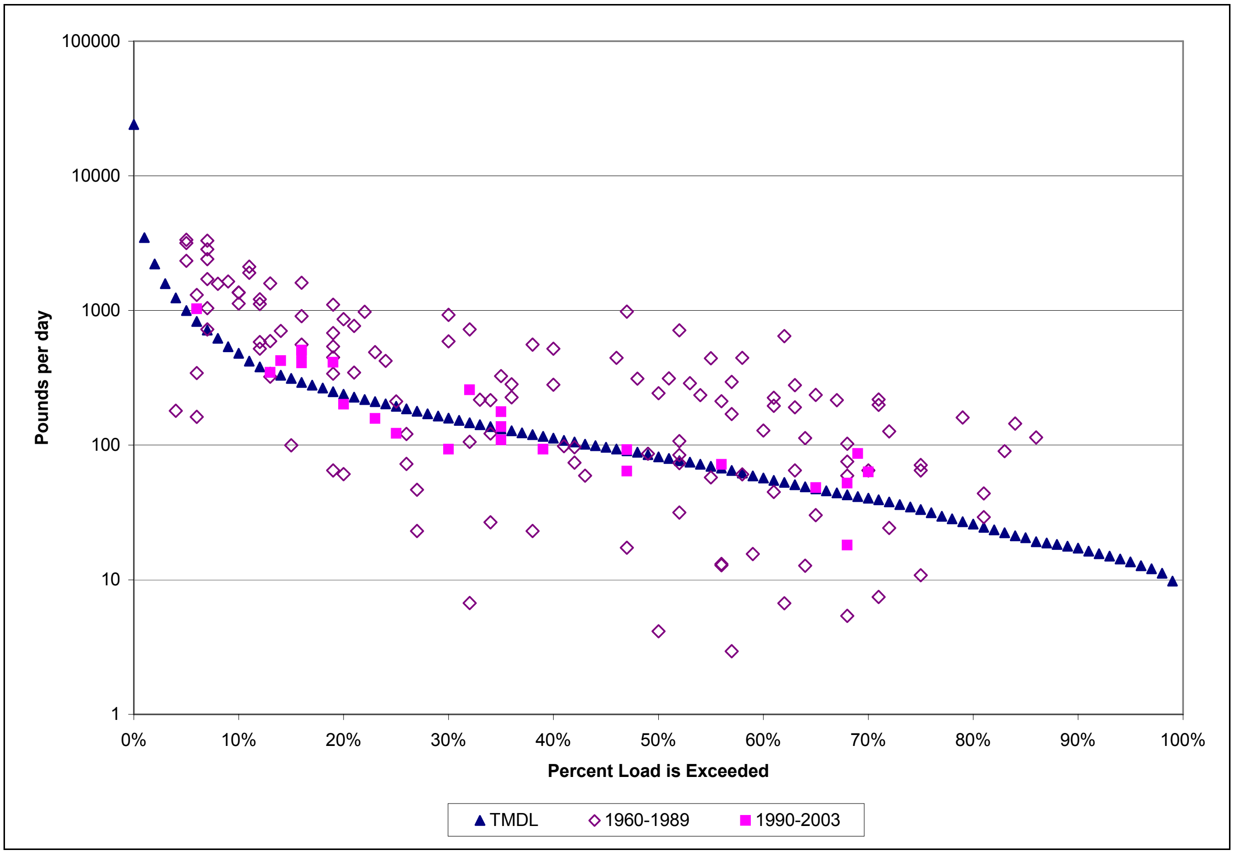
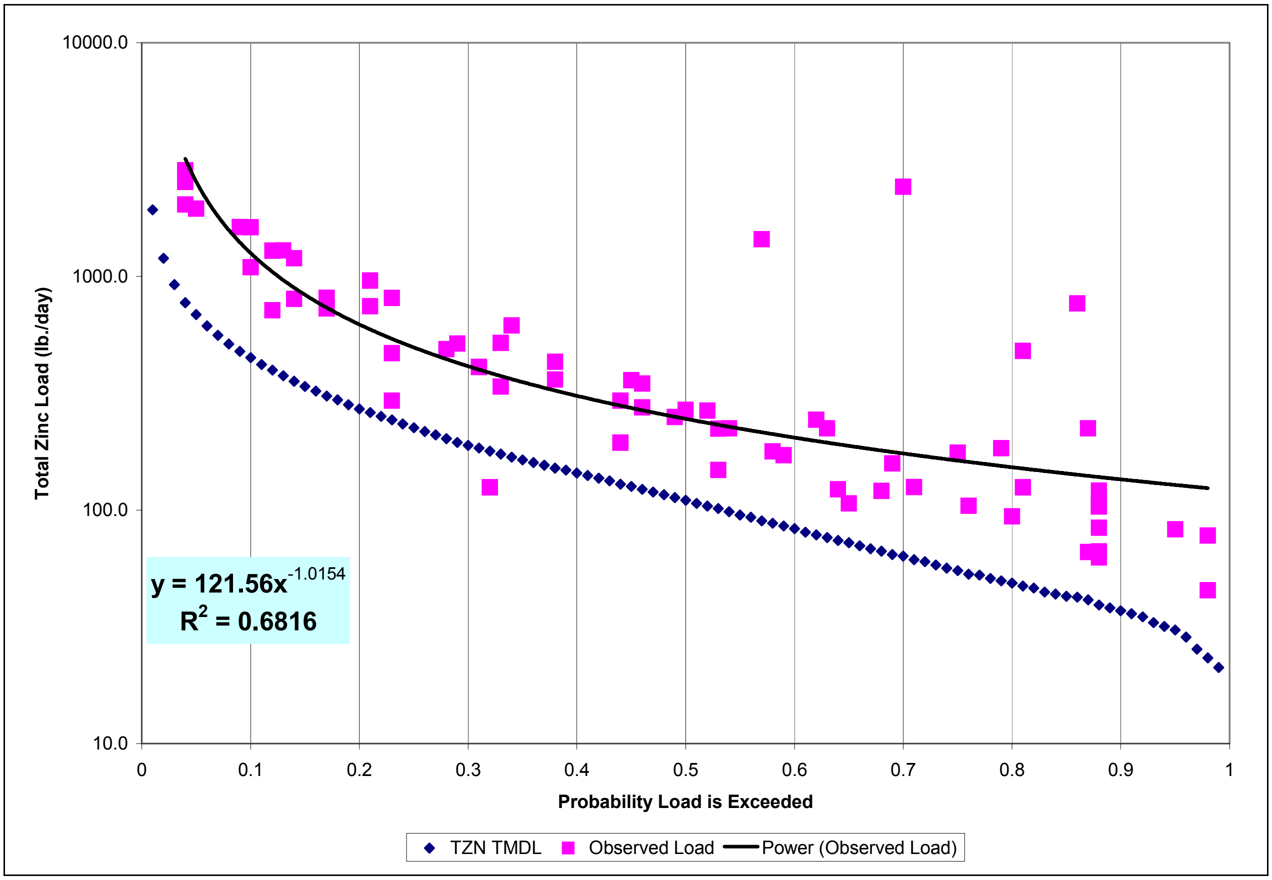


Figure 3: Total Zinc TMDL and Observed Load Measured at USGS 07186480 near Smithfield in Jasper County, Missouri



4.1 Center Creek Load Allocation (Non Point Source Load)

The Load Allocation (LA) is the maximum allowable amount of the pollutant that can be assigned to nonpoint sources. Base flow of Center Creek at the Smithfield Site is estimated at 60 percent, which corresponds to100 ft^3/s (Baseflow Program[18], Arnold et al.). Any loads at low flows (below baseflow) are attributed to zinc coming from known point sources (permitted facilities, see WLA Section 4.2) in this watershed, and seepage from old mines. At higher flows, where contributions from runoff are expected, total zinc concentration appears to remain unchanged (the distance between the observed and TMDL curves in Figure 3). This proportional increase in loading is attributed to runoff. Disturbed old mine lands are prone to water erosion. Such erosion carries soil particles and metal into nearby water bodies. A considerable portion of zinc loading in Center Creek is attributed to runoff from old mine lands in the area.

4.2 Center Creek Waste Load Allocation (Point Source Load)

The Wasteload Allocation (WLA) is the maximum allowable amount of the pollutant that can be assigned to point sources. Although there are several point sources in Center Creek watershed, they were not considered to contribute measurable zinc to the creek. Except for Center Creek WWTF,

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[18] Arnold, J.G, P. M. Allen, R. Muttiah, and G. Bernhart. 1995. Automated base flow separation and recession analysis techniques. Ground Water 33(6):1010-1018.

none of the other permits contain zinc effluent limits or monitoring requirements. Because of this lack of data, there is no way to partition observed load data between point source and nonpoint source contributions at or below baseflow (100 ft^3/s). It is assumed that above baseflow only the loading from runoff increases.

The point sources in the Center Creek drainage area include industrial, wastewater and residential discharges. These facilities are regulated by the state permitting system. This is Missouri's program for administering the National Pollution Discharge Elimination System (NPDES) program. All facilities must obtain a Missouri State Operating Permit and then meet the limits outlined in their permit. The permit holders for point source discharges in the Center Creek basin may be found in Table 2.

Table 2: Permitted Facilities in Center Creek Watershed and Their Potential WLA

		Design Flow		In-Stream Standard		Potential WLA	
NPDES	FACILITY NAME	ft^3/s	MGD	ZN D mg/L	ZN TR mg/L	ZN D Lb./day	ZN TR Lb/day
MO0002402	DYNO NOBEL, INC-CARTHAGE	14.22	9.176	0.148	0.150	11.36	11.51
MO0040185	CENTER CREEK WWTF	7.44	4.8	0.148	0.150	5.94	6.02
MO0113506	EBV EXPLOSIVES ENVIRONMEN	6.59	4.25	0.148	0.150	5.26	5.33
MO0025186	CARL JUNCTION WWTF	1.30	0.840	0.148	0.150	1.04	1.05
MO0040193	CARTERVILLE LIFT STATION	0.74	0.480	0.148	0.150	0.59	0.60
MO0028657	SARCOXIE, CITY OF	0.23	0.15	0.148	0.150	0.19	0.19
MO0002470	SPECIALTY BRANDS, INC.	0.16	0.10	0.148	0.150	0.12	0.13
MO0115169	HICKORY LANE MHP	0.03	0.022	0.148	0.150	0.03	0.03
MO0116882	COACHLIGHT RV PARK	0.01	0.007	0.148	0.150	0.01	0.01
MO0126039	WESTGATE MOBILE HOME PARK	0.01	0.007	0.148	0.150	0.01	0.01
MO0117978	ROGER HINES DUPLEX DEV WW	0.006	0.004	0.148	0.150	0.00	0.01
MO0125857	BRONC BUSTERS WWTF	0.003	0.002	0.148	0.150	0.00	0.00
TOTAL		**30.75**				**24.55**	**24.89**

Note: A facility's potential WLA is calculated at design flow and is not intended to indicate the amount of zinc that is allowable under any conditions. The facility must discharge according to concentration limits in its permit

Center Creek WWTF permit (MO0040185) was modified July 21, 2006, with a daily maximum total recoverable zinc limit of 0.215 mg/L and a monthly average of 0.107 mg/L.

The potential WLA (last column of Table 2) is determined using the design flow of the facility and the target zinc concentration and corresponds to the maximum point source load deliverable to the stream. In practice, these facilities rarely operate at full capacity especially for stormwater outfalls, thus long-tem average flows (and loads) are less than design flow. For this reason, the permit writer has to calculate the effluent limits considering the design flow of a facility, stream 7Q10[19] flow for any available dilution, and the calculated WLA.

Theoretically, most of the outfalls of the permitted facilities discharge stormwater and may not be discharging at low flow.

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[19] 7Q10 is the lowest average flow for seven consecutive days with a recurrence interval of ten years.

4.3 Margin of Safety for Center Creek

A Margin of Safety (MOS) is required in the TMDL calculation to account for uncertainties in scientific and technical understanding of water quality in natural systems. The MOS is intended to account for such uncertainties in a conservative manner. Based on EPA guidance, the MOS can be achieved through one of two approaches:

(1) Explicit - Reserve a numeric portion of the loading capacity as a separate term in the TMDL.
(2) Implicit - Incorporate the MOS as part of the critical conditions for the WLA and the LA calculations by making conservative assumptions in the analysis.

The MOS for the Center Creek TMDL is implicit as expressed in the following conservative approaches:

a. The hardness value chosen for target determination was the 25th percentile of all data in the watershed, which resulted in a smaller criterion value than if only data from Smithville site were used. Graphically, this option shifts the TMDL curve downward.
b. The TMDL is built on data collected since 1963. As demonstrated above (Figure 2), there was a decreasing trend in zinc concentration in the watershed. This decrease in concentration over time resulted largely from better watershed management through several programs and will count toward the MOS.
c. Load reduction is based on comparing the 95^{th} percentile of existing loads within a flow probability range to the target load corresponding to the flow at mid-point of the same range. This approach yields higher reduction than if the average load of observed data was used.

4.4 Load Reduction for Center Creek

Total zinc load is partitioned between loading at baseflow and loading from runoff. Consequently, load reduction to meet WQS must also be partitioned as shown in Table 3 below.

Table 3: Calculated Reduction in Total Zinc Loading for Center Creek over Selected Flow Probability Ranges

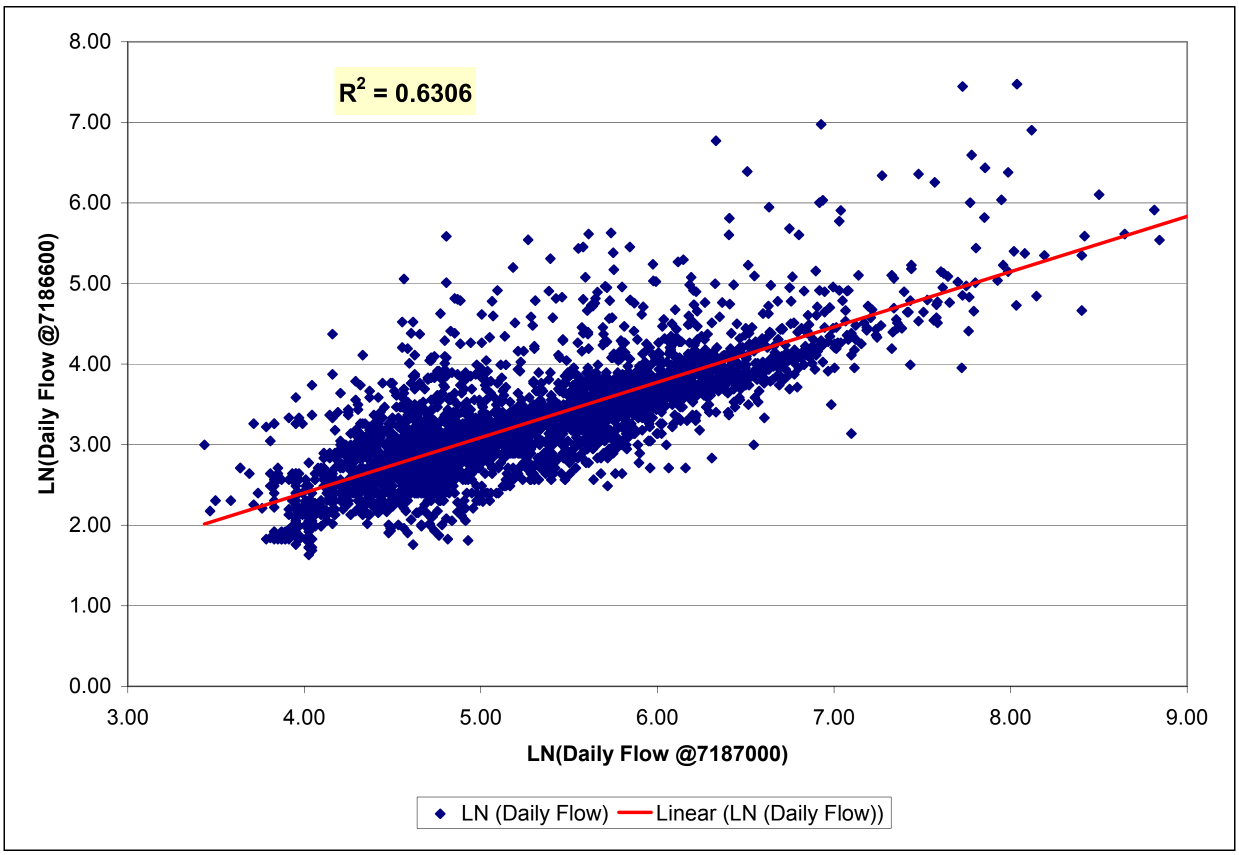
Flow Probability Range	TMDL T Zn lb/day	Existing Load 95th Percentile lb/day	Total Reduction lb/day	PS & Seepage Reduction Percentage	LA-Runoff Reduction Percentage
60- 100%	48	376	328	100%	0%
40-59%	109	1,362	1,253	30%	70%
20-39%	187	1,527	1,340	28%	72%
0-19%	443	3,750	3,307	11%	89%

The reduction in total zinc affects only load allocation (ground seepage, and runoff) at all flow probability ranges. In this calculation, WLA is maintained at 25 lb/day (see Table 2) for all permitted facilities.

5.0 TURKEY CREEK

USGS 07186600 gauging station on Turkey Creek near Joplin drains 41.8 square miles and has daily stream flow records dating from 1963 to 1972. To obtain more recent flow data, gauging station USGS 07187000 on nearby Shoal Creek was used. This station gauges a watershed that drains 427 square miles and provided daily stream flow records from 1924 to 2004. Both stations belong to the same hydrologic unit (11070207) and are less than eight miles apart. Their matched daily stream-flow records exhibit a linear relationship of the form $\text{Log}_{10}(Y) = 0.686 * \text{Log}_{10}(X) - 0.149$ with an $R^2 = 0.636$ (Figure 5). This relation may even be stronger if very high flows were ignored. The average daily flow was synthesized from Nov. 4, 1972 to Sept. 30, 2004 at USGS 07186600, based on this linear relationship. The flow duration curve and resulting load curve for Turkey Creek watershed were founded on data from Jan. 1, 1990 to Sept. 30, 2004.

Figure 4: Daily Flow Relation at two Stations from October 1, 1963 to November 3, 1972
LN(Y) = 0.68*LN(X) – (0.34)



Forty-three hardness records were collected in this watershed (from Turkey Creek and its tributaries) during the period 1976 to 2004. Hardness values ranged from 33 to 561 mg/L with an average of 229, a median of 221, and a 25th percentile of 200 mg/L. The dissolved zinc target was determined using a hardness of 200 mg/L, the 25th percentile as required by rule.

Using the new water quality formula (Section 2.3 Specific Criteria) and a hardness of 200 mg/L, zinc TMDL targets for Turkey Creek watershed are:

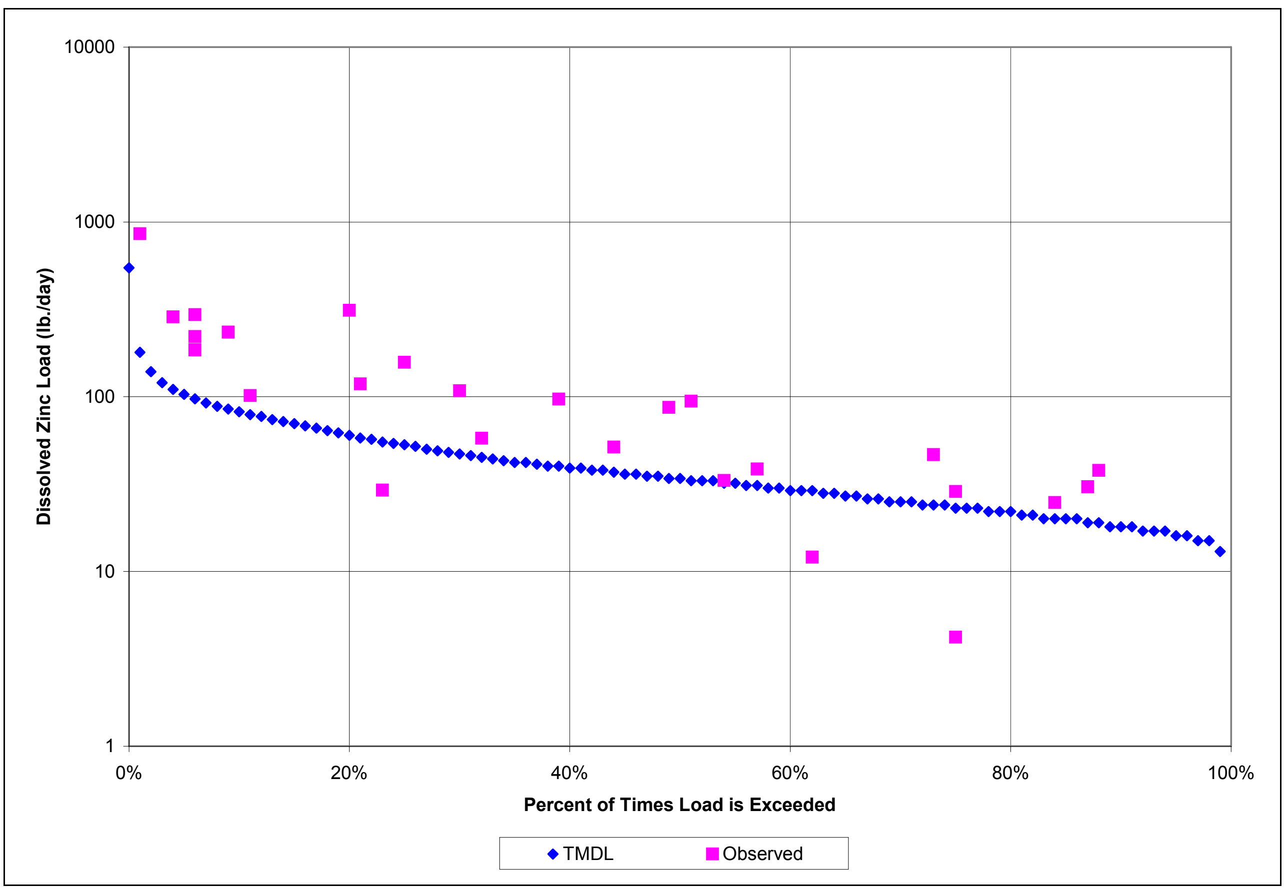
- **Missouri's chronic criterion is 193 μg/L as dissolved, and**
- **Kansas's acute and chronic criteria are 216 μg/L as total**

The corresponding load duration curves and observed loads are drawn in Figures 5 and 6. There are more total than dissolved zinc samples in this watershed (Table 4). Since dissolved zinc is a fraction of total zinc, any load reduction of total zinc will reduce dissolved zinc. For these reasons, and to meet Kansas total zinc criterion at the state line, the TMDL is based on total zinc.

Table 4: Data Summary in Turkey Creek Watershed

	Flow ft^3/s	Hardness mg/L	Total ZN μg/L	Dissolved ZN μg/
Count	258	52	106	92
Mean	37	216	474	381
Minimum	0	30	0	5
Maximum	275	561	2000	1850
Median	26	220	375	289

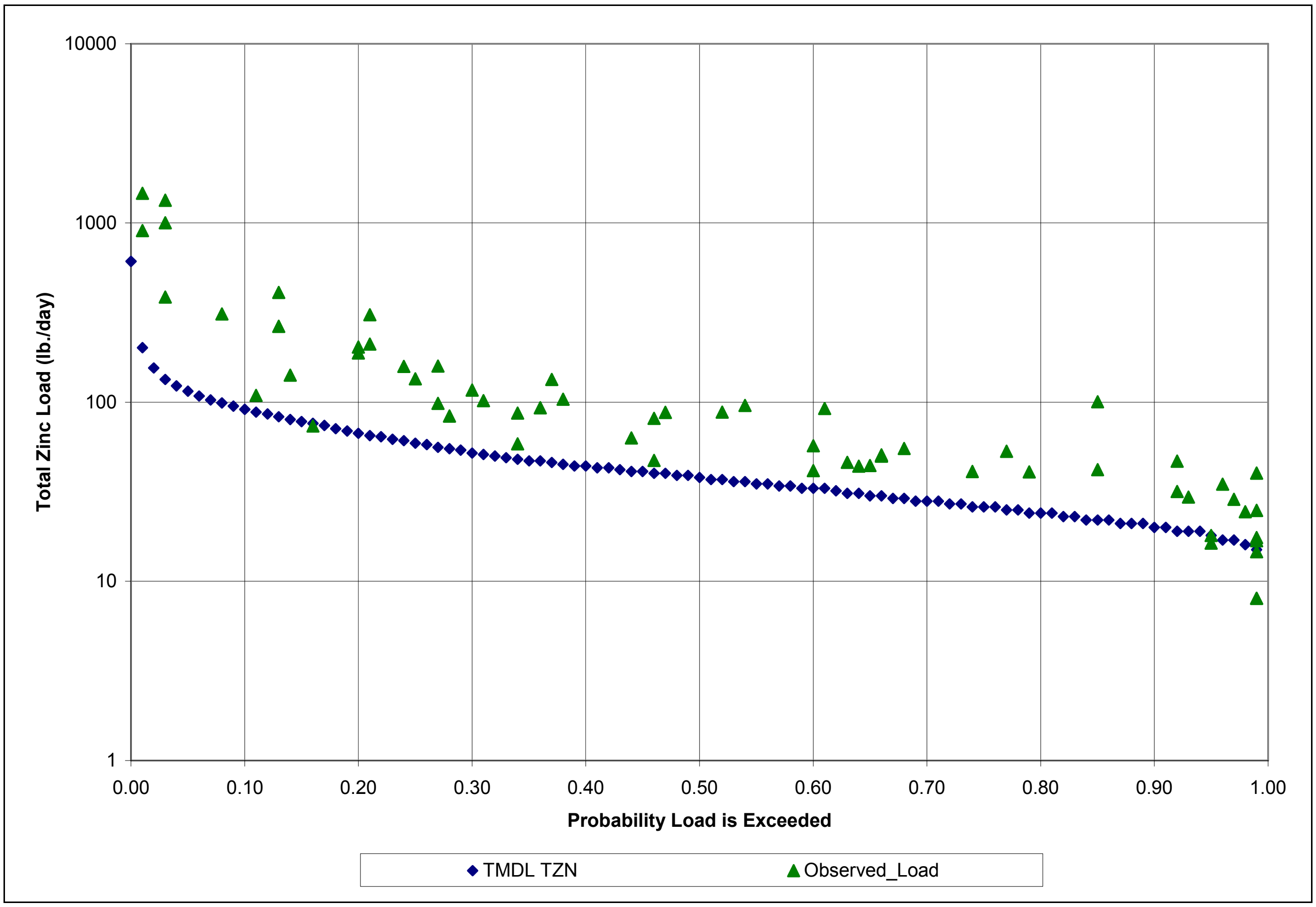
Figure 5: Dissolved Zinc TMDL and Observed Load in Turkey Creek Watershed



5.1 Turkey Creek Load Allocation (Non Point Source Load)

Load Allocation is the maximum allowable amount of the pollutant that can be assigned to nonpoint sources. Figure 5 depicts observed dissolved zinc loads at different flow regimes. Base flow at the outlet of Turkey Creek watershed is estimated to be around 70 percent or 121 ft^3/s.[20] Any loads at low flows (below baseflow) are attributed to zinc coming from known point sources (permitted facilities, see WLA Section 5.2) in this watershed, and seepage from old mines. Total zinc concentration of 1,000 µg/L or more were recorded prior to 1989. This fact indicates that these high spikes are less common in recent years due to reclamation efforts and better watershed management.

Figure 6: Total Zinc TMDL and Observed Load in Turkey Creek near Joplin, Missouri



5.2 Turkey Creek WLA (Point Source Load)

The Wasteload Allocation (WLA) is the maximum allowable amount of the pollutant that can be assigned to point sources. The point sources in Turkey Creek drainage areas include industrial, wastewater and residential discharges. These facilities are listed in Table 5.

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[20] Arnold, J.G, P. M. Allen, R. Muttiah, and G. Bernhart. 1995. Automated base flow separation and recession analysis techniques. Ground Water 33(6):1010-1018.

Table 5: Point Source Discharges in Turkey Creek Watershed

Permit Number	Facility Name	Design Flow MGD	Design Flow ft^3/s	Receiving Stream (Turkey Creek and its tributaries)
MO-0002348	Eagle-Picher Industries	3.5	5.4	Lone Elm to Turkey Cr.
MO-0102253	Fibrex Inc.	0.061	0.09	Trib to Lone Elm
MO-0111325	International Paper – Joplin	1.0	1.5	Joplin Creek to Turkey Creek/Short Creek
MO-0108731	Joplin Landfill	Stormwater		Trib to Turkey Creek
MO-0103349	Joplin/Turkey Cr. WWTF	15.0	23.25	Turkey Creek
MO-0116858	Missouri Steel Castings	Stormwater		Trib to Turkey Creek
MO-0093998	Tamko Roofing	Varies		Turkey Creek
MO-0002411	Vickers/Eaton Hydraulics	0.9	1.4	Turkey Creek/Short Cr.

Note: MGD = Million Gallons per Day; ft^3/s = cubic feet per second

Fibrex Inc. and Tamko Roofing do not have any zinc monitoring or limits as a part of their state operating permits. International Paper has monitoring only. The other facilities have zinc limits, which are listed in Table 6.

Table 6: Facilities in Turkey Creek Watershed with Zinc Limits ("old criteria")

Permit Number	Facility Name	Zinc Permit Limits (daily maximum) Dissolved mg/L	Zinc Permit Limits (daily maximum) Total Recoverable mg/L
MO-0002348	Eagle-Picher Ind.	<u>1.64</u>	1.18, 1.66 or 2.12 related to water hardness
MO-0108731	Joplin Municipal Landfill	<u>0.37</u>	0.38
MO-0103349	Joplin/Turkey Creek WWTP	<u>0.65</u>	0.66
MO-0116858	Missouri Steel Castings	<u>0.56</u>	0.57
MO-0002411	Vickers/Eaton Hydraulics	0.44	Monitoring only

<u>Underlined numbers</u> = Permit limit of dissolved zinc, when not set, was derived from the limit of total recoverable using the appropriate formula. Zn D=0.986*ZnTR

According to many studies (See Addendum), the aquatic habitat and water quality in both Center Creek and Turkey Creek have been severely affected by point source discharges in the past. As upgrades have occurred, metals contamination from these point sources has decreased. Present loads from point sources on Turkey Creek, listed in Table 7, are based on current zinc limits using the following formula:

(WWTF design stream flow in ft^3/sec)(dissolved zinc in mg/L)(5.395*)= pounds/day

**5.395 is the constant used to convert ft^3/sec times mg/L to pounds per day.*

Table 7: Estimation of Existing Load Based on Current Effluent Limits and a Hardness of 200 mg/L

		Design Flow	Permit Limit (Daily Max)		Load	
Permit #	FACILITY NAME	ft^3/s	ZN D mg/L	ZN TR mg/L	ZN D Lb./day	ZN TR Lb./day
MO-0002348	Eagle-Picher Industries	5.4	1.64	1.18, 1.66, 2.12	47.7	48.4
MO-0111325	International Paper	1.5	Monitoring	Monitoring		
MO-0103349	Joplin, Turkey Creek WWTF	23.25	0.65	0.66	82	83
MO-0108731	Joplin Municipal Landfill	Varies	0.37	0.38		
MO 0116858	Missouri Steel Castings	Varies	0.56	0.57		
MO-0002411	Vickers/Eaton Hydraulics	1.4	0.44	Monitoring	3	13
TOTAL (Pounds per day)					**133**	**144**

Note: All design flows are rainfall dependent, except for Joplin Turkey Creek WWTF
ZN D = dissolved zinc
ZN TR = total recoverable zinc

From their discharge monitoring reports (DMR), these facilities seem to operate within their current limits. However, these limits may not be stringent enough to meet the new zinc criterion. DMR data collected during 2000-2004 period were averaged in Table 8.

Table 8: Summary of DMR Data (2000-2004 averaged)

		Design Flow	Concentration		Estimated Load	
PERMIT #	FACILITY NAME	ft^3/s	ZN D mg/L	ZN TR mg/L	ZN D lb/day	ZN TR lb/day
MO0002348	Eagle-Picher Industries	5.4	0.32	0.32	9	9
MO0111325	International Paper	1.5	7.06	7.16	57	58
MO0002411	Vickers/Eaton Hydraulics	1.4	0.685	25.8	5	195
MO0103349	Joplin, Turkey Creek WWTF	23.25	0.15	0.15	19	19
MO0108731	Joplin Municipal Landfill	Varies				
MO0116858	Missouri Steel Castings	Varies				
TOTAL (Pounds per day)					90	281

Note that DMR data did not contain flow measurement. Thus the estimated load is based on the design flow.

Table 9: Estimated WLA in Turkey Creek Watershed ("new criterion")

		Design Flow	Permit Limit (Daily Max)		WLA	
PERMIT #	FACILITY NAME	ft^3/s	ZN D mg/L	ZN TR mg/L	ZN D Lb./day	ZN TR Lb/day
MO0002348	Eagle-Picher Industries	5.4	0.19	0.216	5.6	6.3
MO0111325	International Paper	1.5	0.19	0.216	1.6	1.7
MO0002411	Vickers/Eaton Hydraulics	1.4	0.193	0.216	1.5	1.6
MO0103349	Joplin,Turkey Creek WWTF	23.25	0.19	0.216	24.2	27.1
MO0108731	Joplin Municipal Landfill	Varies	0.19	0.216		
MO0116858	Missouri Steel Castings	Varies	0.19	0.216		
TOTAL (Pounds per day)					**33**	**37**

This WLA will be reflected in the permits for point sources in the Turkey Creek watershed. It is represented in Figure 9 (Page 25) and used to calculate load reduction in Table 10.

5.3 Load Reduction for Turkey Creek Watershed

If effluent limits for the permitted facilities in this watershed were modified to reflect zinc WLA (0.216 mg/L of total zinc for a hardness of 200 mg/L), the corresponding potential load would be about 37 pounds per day (Table 9). This load is used in Table 10 to calculate seepage reduction.

Figure 7: Load Partition

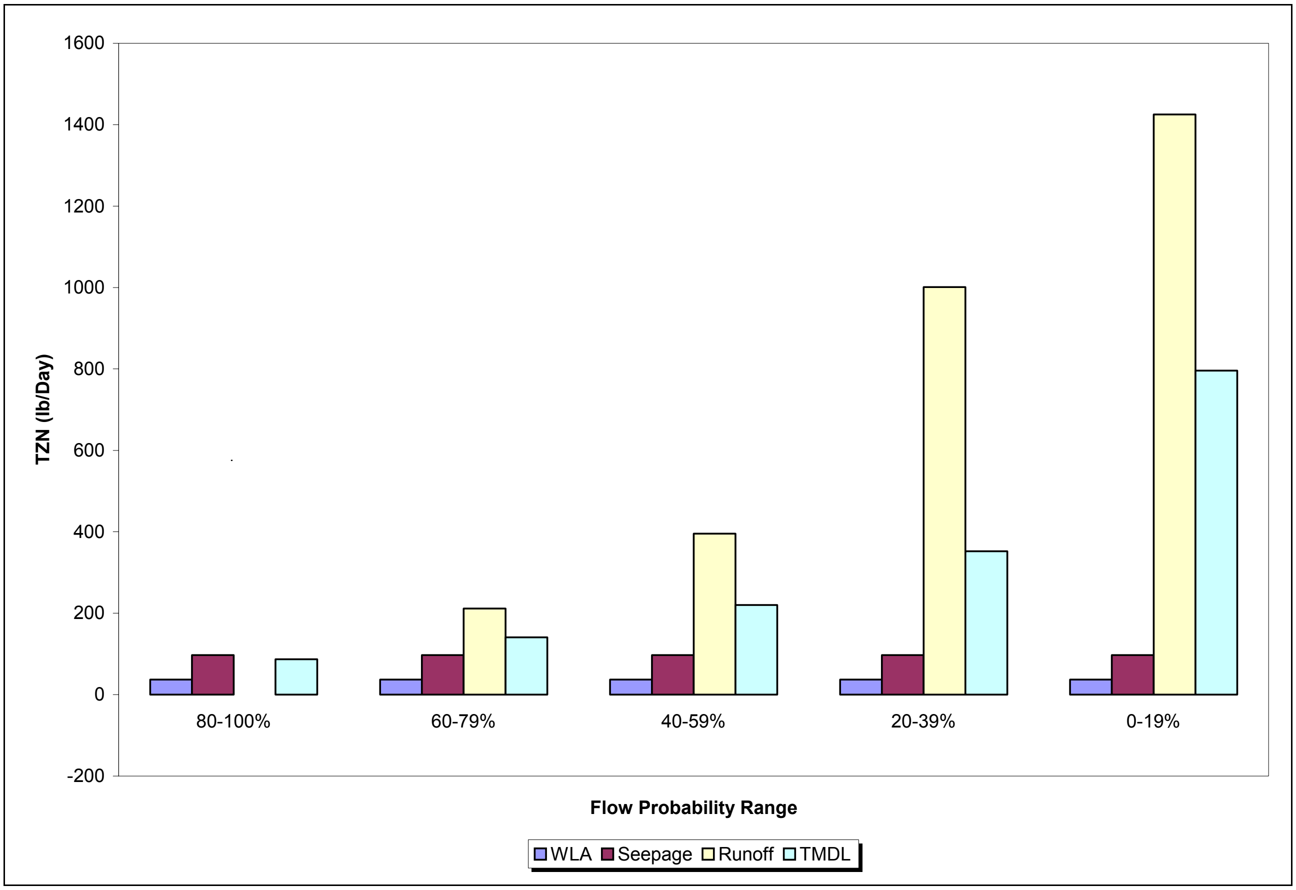


Table 10: Calculated Reduction in Total Zinc Loading for Turkey Creek over Selected Flow Probability Ranges

Flow Probability Range	TMDL TZn lb/day	Existing Load 95th Percentile lb/day (Cumulative Data)	Total Reduction Required lb/day	PS & Seepage Reduction %	LA Runoff Reduction %
70-100%	99	182	83	100%	0%
60-69%	158	345	187	97%	3%
40-59%	220	530	310	59%	41%

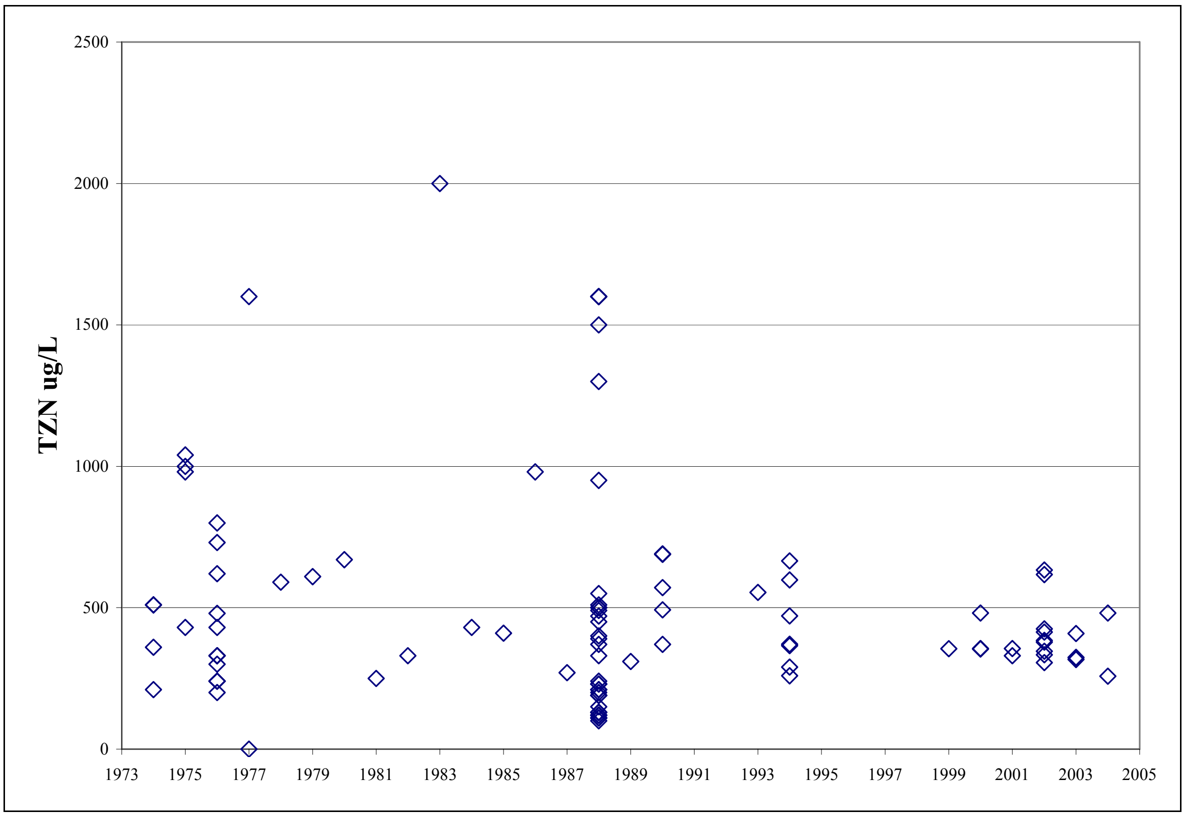
20-39%	352	1135	783	23%	77%
0-19%	796	1559	763	24%	76%

Note: Because of the amplitude irregularity of observed data, the 95th percentile for any probability range is calculated using all samples up to and including that range.

5.4 Margin of Safety (MOS) for Turkey Creek

A conservative MOS was used for the Turkey Creek TMDL. It consisted of using the 25th percentile of hardness data instead of the average or median. A lower hardness value yields a more stringent zinc criterion. In addition, over the period of records there is a negative trend in total zinc concentration as shown in Figure 8. On average, total zinc load is lower across flow regimes during the period 2000-2004 than during 1974-1999. Since load reduction is based all available data, this trend will add to the MOS.

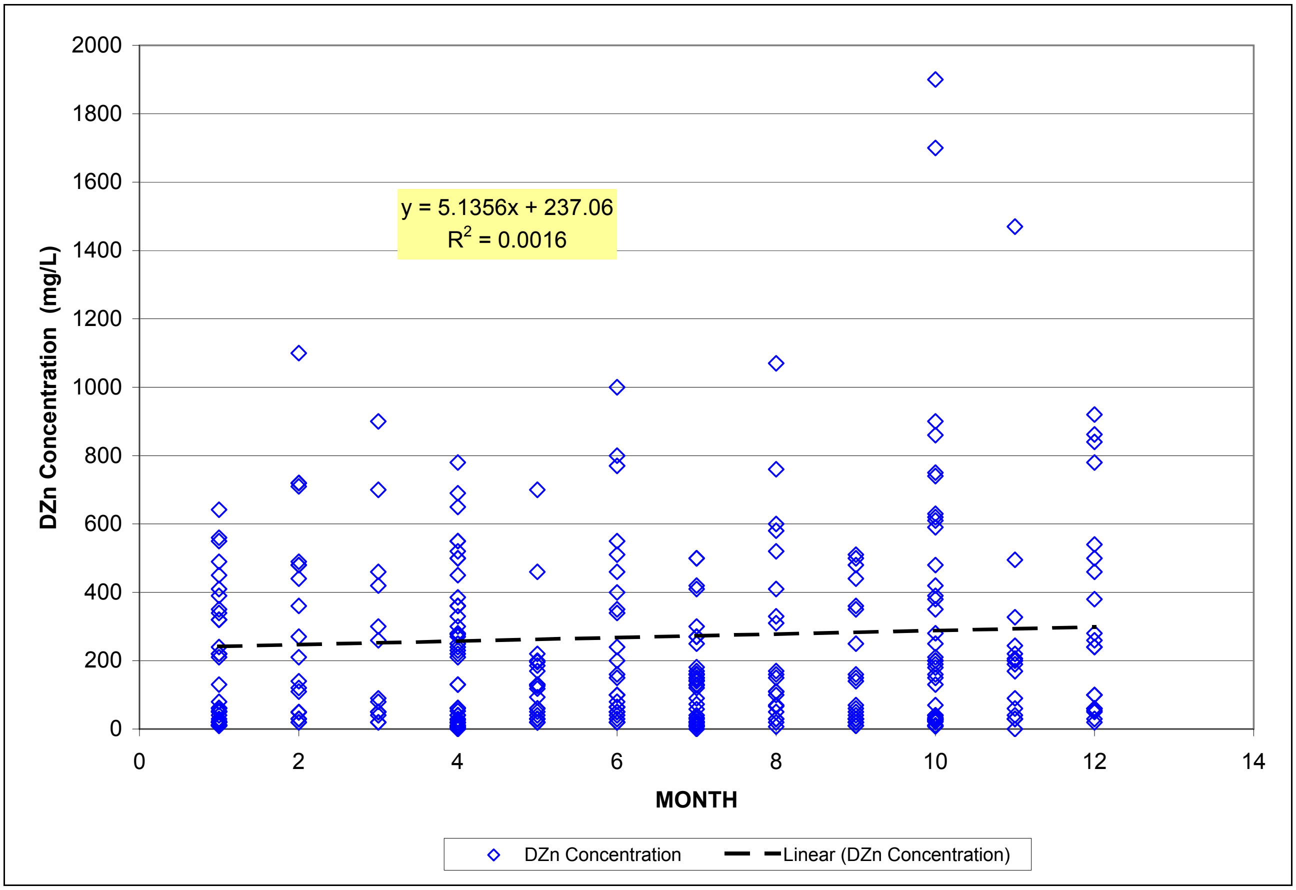
Figure 8: General Trend over Time of Total Zinc Concentration in Turkey Creek Watershed



6.0 SEASONAL VARIATION

The availability of zinc in the environment is regulated through chemical reactions. Seasonal forces such as temperature are not expected to play a significant part. Flow regime is seasonal and directly related to precipitation. The flow is highest in the spring and lowest in the summer. Concentration on the other hand, tends to be independent of seasons and therefore, remains constant all year-round. This is illustrated in Figure 9, using data from the Center Creek watershed. Because these TMDLs are expressed in a loading curve, a different load corresponds to every flow probability, but a constant concentration applies all year-round.

Figure 9: Zinc Concentration Monthly Distribution in Center Creek Watershed



7.0 MONITORING PLAN FOR TMDLS DEVELOPED UNDER THE PHASED APPROACH

To monitor the overall health of these watersheds, the Department of Natural Resources scheduled a low-flow study for 2006 for Center and Turkey creeks and their tributaries. Also, the USGS maintains annual ambient monitoring in Center Creek near Smithfield and in Turkey Creek near Joplin. To assess the impact of the point sources, the TMDL will require zinc monitoring to be included in the permits of all dischargers to these two watersheds.

As with all of Missouri's TMDLs, if continuing monitoring reveals that WQS are not being met, the TMDL will be reopened and re-evaluated accordingly. This TMDL will be incorporated into Missouri's Water Quality Management Plan.

8.0 IMPLEMENTATION PLANS

8.1 Point Sources

For the point sources, effluent limits will be revised, where appropriate, to reflect zinc WLA determined in this document. All permitted facilities in either the Center or Turkey Creek watershed shall be required to monitor effluent dissolved zinc concentration and receiving stream hardness. Also, storm water drainage area management should be reevaluated. This might involve improving existing controls or adding new ways to reduce erosion.

8.2 Nonpoint Sources

The old lead mining area in Jasper County was placed on the National Priorities List as a Superfund site in 1991. Restoration methods were evaluated through pilot projects in the watershed. Remediation activities have included closing shafts, returning mined materials to the subsurface (subaqueous disposal) and preventing erosion by grading and revegetating chat piles. Natural Resource Damage assessment and restoration also plays a part in site remediation. The Potential Responsible Parties, the EPA and the department are funding these efforts. Water quality monitoring continues on a regular basis.

Under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) commonly called Superfund, the department and other state and federal agencies have already accomplished a lot in cleaning up the sites that contribute to heavy metals contamination of these creeks. Work has also been done to mitigate the impact on the population living in or near these areas. EPA and various state(s) environmental agencies have conducted these cleanup actions in the Tri-State Historic Mining District since the mid-1990s. The following is a list of cleanup actions conducted through May 2005 in the Oronogo-Duenweg Mining Belt Site in Jasper County.

- Excavation and replacement of lead and cadmium contaminated yard soil at 2,600 residential properties, public parks, schools and childcare centers.
  - Completion of Lead and Cadmium Exposure Studies conducted before and after residential yard soil cleanup. These studies showed 75 percent reduction in child blood-lead levels.
- Installation of over 70 miles of public water supply lines and connection of over 550 residences with contaminated private drinking water supply wells to the public water systems.
- Closure by the department of 50 dangerous mine shafts.
- Implementation of Ground Water Institutional Controls for regulating the drilling of private water supply wells to prevent construction of wells in contaminated aquifers, and to prevent cross contamination from the upper contaminated aquifer into the lower uncontaminated aquifer.
- Utilization and covering of several thousand cubic yards of mine waste beneath the Highway 249 road bed during construction of the highway.
- Completion of the Environmental Master Plan to guide future development in Jasper and Newton counties.
- Establishment of the Environmental Contamination Ordinance by Jasper County for regulation of development on contaminated land.

Additionally, numerous investigations, treatability studies and risk assessments have been completed (below). These studies are on file with the department's Hazardous Waste Program.

- The Remedial Investigation, 1995
- Feasibility Study for the mining waste, 2003
- The Human Health and Ecological Risk Assessment, 1998 (Record of Decision: clean up 7,000 acres in 8-10 years)
- The Biosolids Treatment and Revegetation Study

- Phosphate Treatment Bioavailability Study, 2004
- Subaqueous Disposal Treatability Study, 2004

As already stated, the remediation of the Tri-State Historic Mining District is taking place under CERCLA (Superfund). Even with all the work already accomplished, there is more to be done and this is a very long-term project. Work still to be completed includes removing or containing the remaining chat piles and dealing with chat and tailings that are clogging and contaminating the creeks.

It is worth noting that local citizens have been very involved with the cleanup of these mining sites. During the actual cleanup years (soil removal, etc.), residents formed the Jasper County Task Force and the Technical Assistance Group (TAG). They worked with EPA and the department performing the cleanup. The TAG reviewed all documents. The groups were made up of about 40 citizens from the area. The Task Force included community leaders, mayors, city officials, county health department, other interested citizens and representatives from the TAG. They helped develop educational programs for schools and made suggestions and comments about documents and plans for different stages of the removal actions. In 1998, the TAG and the Task Force merged into the Jasper/Newton Counties Environmental Task Force. The Environmental Task Force includes representatives from every interested community in the two counties and has a goal to prevent future environmental problems by looking at the full scope of potential problems, not just mining cleanup.

In March 2005, the Tri-State Watershed Forum began and will enable all parties involved in cleaning up the district to work together to resolve the problems in this huge area. The effort includes the departments of Natural Resources and Conservation in Missouri and their equivalents in Kansas, Oklahoma and nine Native American Tribes in Oklahoma, two EPA regions, U.S. Army Corps of Engineers' districts, U.S. Geological Survey and the U.S. Fish and Wildlife Service. Working together should reduce duplication of projects, give everyone access to all work that has already been completed, foster cooperation and make corrective action more efficient and cost effective. Mr. Mark Doolan, EPA Region 7, Superfund, is spearheading this effort. In a "stakeholder" meeting in Joplin on March 2, 2005, Mr. Doolan presented a Strategy Framework for accomplishing this. The federal and state agencies, departments and tribes met again during the Tri-State Historic Mining District Forum in Joplin on April 12-14, 2005. The goals of this forum were to promote awareness, increase coordination/optimize activities and share technical information. The first phase of the framework is to deal with the Superfund issues. The second phase will include a watershed plan to deal with all non-Superfund site related issues, such as flooding, habitat improvements, phosphorus, bacteria, nitrates, CAFOs and sediment. This second phase fits with the Environmental Task Force's goals and objectives.

9.0 REASONABLE ASSURANCES

In most cases, "Reasonable Assurance" in reference to TMDLs relates only to point sources. As a result, any assurances that non-point source (NPS) contributors of zinc will implement measures to reduce their contribution in the future, will not be found in this section. Instead, discussion of reduction efforts relating to NPS can be found in the "Implementation" section of this TMDL.

10.0 PUBLIC PARTICIPATION

These water quality limited segments of Center and Turkey creeks are included on the approved 2002 303(d) list for Missouri. After the department develops a TMDL, it is placed on notice for public review. The 30-day public notice period for the draft Center and Turkey Creeks TMDL was from May 5, 2006 to June 4, 2006. Groups that received the public notice announcement included the Missouri Clean Water Commission, affected point sources, the Water Quality Coordinating Committee, Tri-State Mining Historic District coordinators, Kansas Department of Health and the Environment, Oklahoma Department of Environmental Quality, affected Native American Tribes, the 105 Stream Team volunteers in the county and the seven area legislators. Also, the department posted the notice, the Center Creek and Turkey Creek Information Sheets and this document on its Web site, making them available to anyone with access to the Web. The department has placed a copy of the notice, the comments received and its responses in the Center and Turkey creeks file.

11.0 APPENDICES

Addendum – A list of studies on Center and Turkey Creeks from 1958 to 1997
Appendix A – Land Use Maps for Center and Turkey Creeks
Appendix B – Topographic maps showing the impaired segments and sampling sites
Appendix C – Stream Hardness Frequency Distribution Graphs
Appendix D – Water quality data used in modeling Center and Turkey Creeks

12.0 DOCUMENTS ON FILE WITH THE DEPARTMENT

All of the studies listed in the Addendum
Permits for the dischargers to both watersheds
Record of Decision for Oronogo-Duenweg mining area (HWP)
Strategy Framework from the Tri-State Watershed Forum meeting of March 2, 2005

13.0 REFERENCES

Arnold, J.G, and P.M. Allen. 1999. Automated methods for estimating baseflow and ground water recharge from streamflow records. Journal of the American Water Resources Association 35(2): 411-424.

Kansas Department of Health and Environment Water Quality Standards.
http://www.kdhe.state.ks.us/water/download/kwqs_plus_supporting.pdf

Missouri Department of Natural Resources Water Quality Standards.
http://www.sos.mo.gov/adrules/csr/current/10csr/10c20-7.pdf

U.S. Environmental Protection Agency (EPA). Federal Water Quality Standards for Waters in Indian Country. http://epa.gov/waterscience/tribes/regs.htm

ADDENDUM

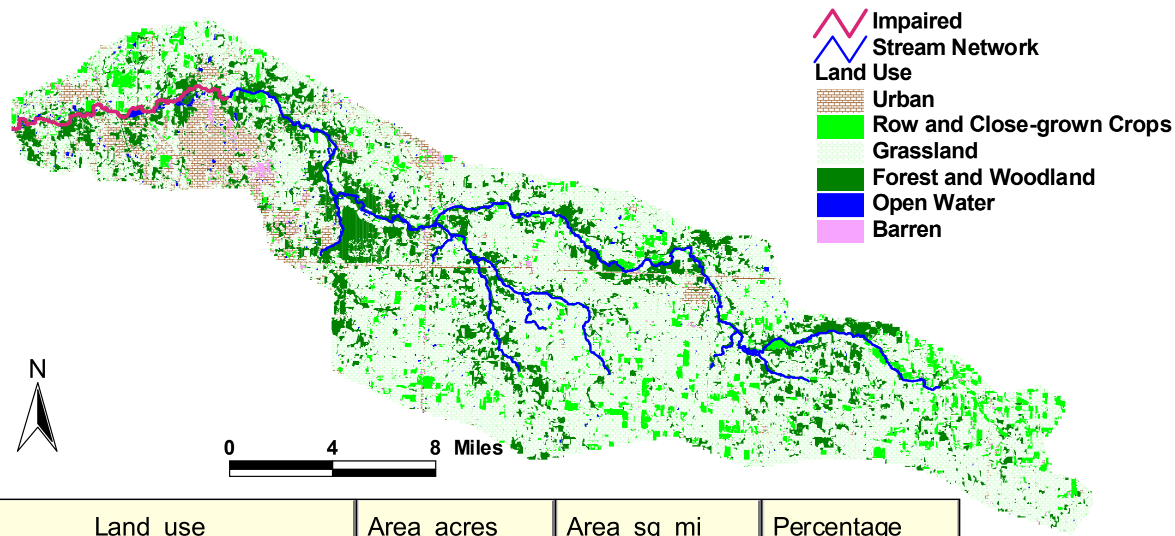
A partial list of known studies on Center and Turkey Creeks from 1958 to 1997, with a synopsis of each

- Missouri Water Pollution Board, Spring River Basin, Shoal – Turkey Creek: A Water Quality Study, 1958-1959. This study examined physical features, chemical features and biological features and determined that Turkey Creek was too small to assimilate the amount of wastewater being discharged to it without impairing water quality.
- Biological Studies of Center and Grove Creeks for the Atlas Powder Company, March 1961, The Academy of Natural Sciences of Philadelphia, Department of Limnology, 1961. This study examined the chemical and biological features of Center and Grove Creeks. It found one sample location on Center Creek indicative of a healthy stream, one location on Center Creek showed signs of degradation due to contamination from Grove Creek. and the sample location on Grove Creek to be severely polluted—to the extent there was an almost complete absence of living organisms.
- Water Resources of the Joplin Area, Mo., Water Resources Report 24, Feder G.L., Skelton J., Jeffery, H.G., Harvey, E.J., Missouri Geological Survey & Water Resources, 1969. This large study covered hydrology, geology, history, water sources, and possible development potential for area ground and surface water in the Spring River basin.
- Biological Recovery of Center Creek with Notes on the Effects of Zinc Pollution. Howland, J.R., Missouri Department of Natural Resources, 1974. This study of the benthic macroinvertebrate community in Center Creek found that following upgrade of the discharges by industry on Grove Creek, some measure of recovery had occurred.
- Water Quality: James, Elk, Spring River basins, Missouri Clean Water Commission, 1974. This study of hydrologic characteristics, benthic community, and physical, chemical and bacterial quality in the James, Elk, and Spring River basins found Center Creek downstream from the mouth of Grove Creek to be seriously polluted from industrial discharges and abandoned mine land runoff. It concluded that Turkey Creek was little changed from the water quality found in the 1958-1959 study mentioned above.
- Water Quality Survey of the Elk, James and Spring River Basins of Missouri, 1964-1965, Dieffenbach, W. and Ryck, Jr., F. Missouri Department of Conservation, 1976. This study of the density, diversity and composition of benthic invertebrates determined that Center Creek was seriously polluted for 17 miles by industrial effluents and by zinc contamination from abandoned mine land. Turkey Creek was described as grossly polluted for 6 miles by effluent from the Joplin sewage treatment plant.
- Alternatives for Control of Drainage from Inactive Mines and Mine Waste Areas, Joplin Area, Missouri, Watner, D.L., Ozark Gateway Council of Governments, Joplin, Missouri, 1977. This study examined alternative remediation methods for mine drainage in the Center and Turkey Creek watersheds.
- Effects of Abandoned Lead and Zinc Mines and Tailings Piles on Water Quality in the Joplin Area, Missouri, Barks, J.H., U.S. Geological Survey, 1977. This study evaluated the extent to which abandoned mines and tailings affected ground and surface water quality in Center and Turkey Creeks. It found high concentrations of zinc at sample locations on both creeks.

- Water Resources Contamination from Abandoned Zinc-Lead Mining-Milling Operations and Abatement Alternatives, Ozark Gateway Council of Governments, 1980. This study found that mine-related discharges had high levels of calcium, sulfate, and soluble metals, primarily zinc, which was suspected to be biologically toxic to aquatic plants and animals. A variety of alternative treatments for remediation were proposed.
- 1983-1985 Quantitative Studies of Benthic Macroinvertebrates in Center Creek, Missouri for Atlas Powder Company, Joplin, Missouri, Report No. 86-12, Academy of Natural Sciences of Philadelphia, 1986. This study measured benthic macroinvertebrates at three stations on Center Creek. It found that water quality was being negatively affected by the addition of water from Grove Creek. It suggested that water quality, however, was improving due to processing changes made by the point source discharger on Grove Creek.
- Assessment of Water Quality in Non-Coal Mining Areas of Missouri, Smith, B.J. Smith, U.S. Geological Survey, Water-Resources Investigations Report 87-4286, 1988. This study examined existing literature to determine whether mining of non-coal minerals in Missouri has caused or could cause adverse changes in water quality in the mined areas.
- Water-Quality Characterization of the Spring River Basin, Southwestern Missouri and Southeastern Kansas, U.S. Geological Survey, Water-Resources Investigations Report 90-4176, 1992. This study analyzed existing data collected in previous studies and reported that high levels of zinc in Center and Turkey Creeks resulted in the absence of any benthic invertebrate community, and that Turkey Creek was probably adversely affected by wastewater plant discharges.
- Draft Remedial Investigation Neck/Alba, Snap, Oronogo/Duenweg, Joplin, Thomas, Carl Junction, and Waco Designated Areas, Jasper County Site, Jasper County, Missouri, Dames & Moore, 1994. This study is a draft in partial fulfillment of consent decree requirements for the U.S. Environmental Protection Agency. It summarizes and evaluates data collected during investigation of drinking water supplies from a shallow aquifer.
- Spring River Watershed Inventory and Assessment, Kiner, L.K., et al, Missouri Department of Conservation, 1997. An exhaustive study of the Spring River Watershed with information on land use, water quality, biotic community, geology, hydrology, habitat conditions, management alternatives, and an angler guide.

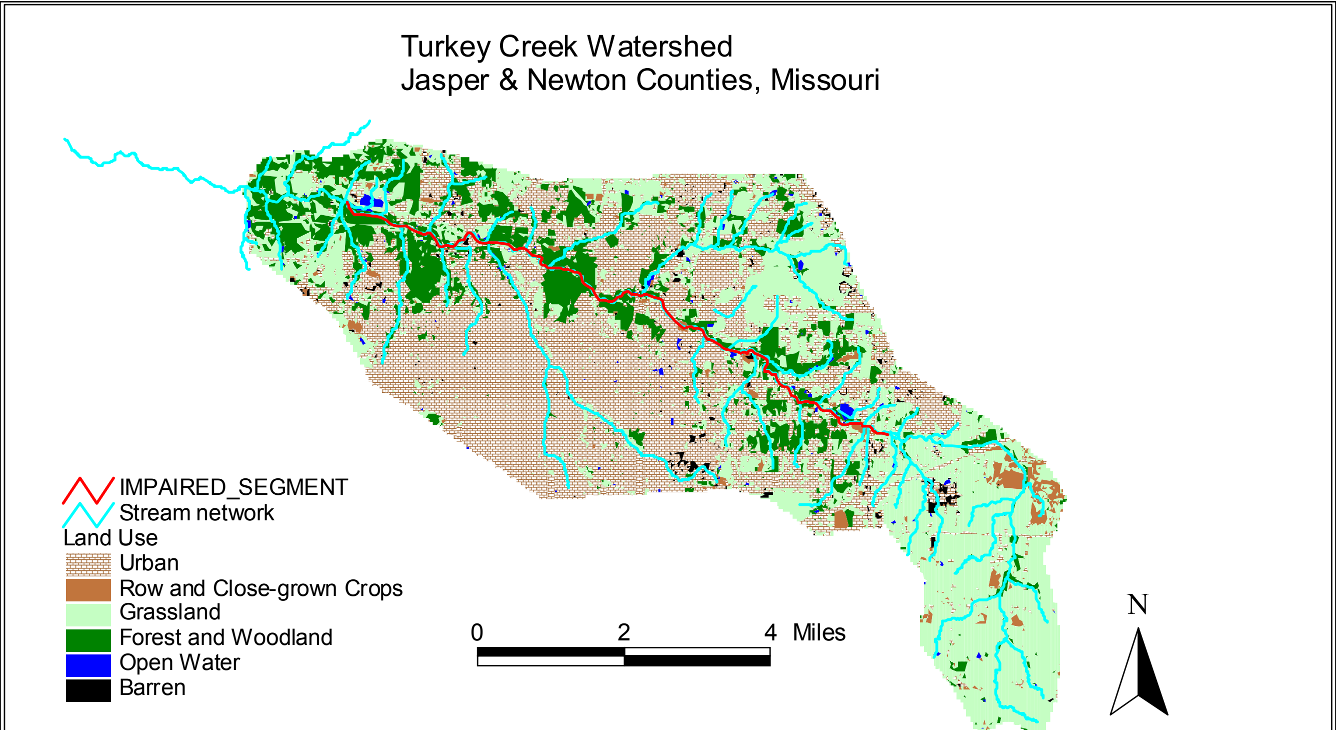
Appendix A-1. Center Creek Land Use Map

Center Creek Watershed Land Use (2000)
Jasper, Newton, & Lawrence Counties, MO



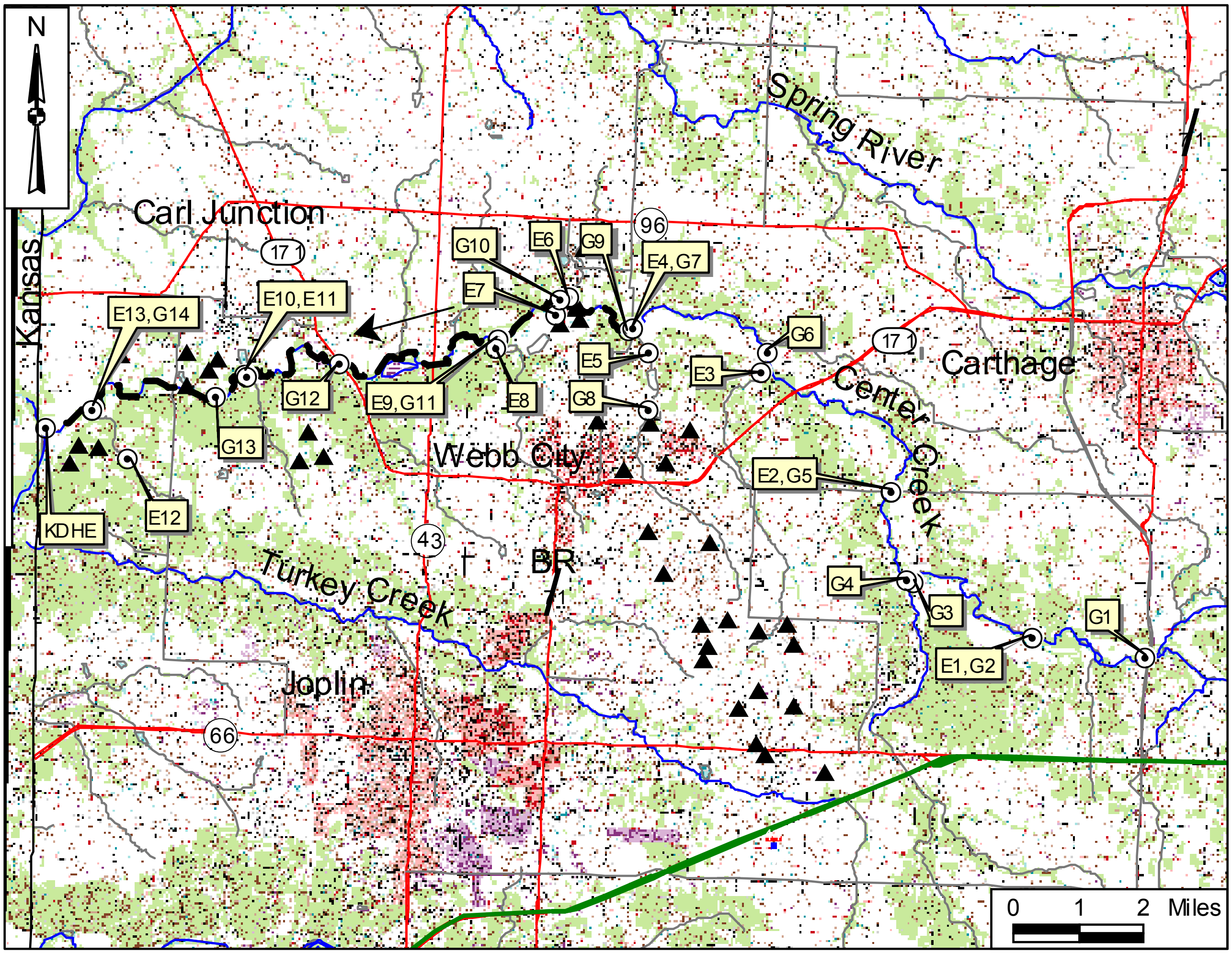
Land_use	Area_acres	Area_sq_mi	Percentage
Urban	13916	21.7	7
Row and Close-grown Crop	17700	27.7	9
Grassland	122275	191.1	63
Forest and Woodland	35845	56.0	19
Open Water	1691	2.6	1
Barren	1244	1.9	1
TOTAL	192672	301.1	100

Appendix A-2. Turkey Creek Land Use Map



Land_use	Area_acres	Area_sq_mi	Percentage
Urban	1684	2.6	17
Row and Close-grown Crop	1356	2.1	14
Grassland	5247	8.2	53
Forest and Woodland	1375	2.1	14
Open Water	253	0.4	3
Barren	24	0.0	0
TOTAL	9940	15.5	100

Appendix B-1.
Water Quality Monitoring Sites in Center and Turkey Creeks Watersheds



Index to Sites

US-EPA

E1 – Center Creek 2 miles below Fidelity
E2 – Center Creek at Highway HH 1.5 miles below Grove Creek
E3 – Stout's Branch near mouth
E4 – Center Creek 0.1 mile above Mineral Branch
E5 – Mineral Branch 0.5 mile above mouth
E6 – Tributary to Center Creek at Oronogo, near mouth
E7 – Malibu Pit resurgence
E8 – Center Creek 1.5 miles below Oronogo Branch
E9 – Tributary to Center Creek 1.5 miles below Oronogo, near mouth
E10 – Center Creek at Carl Junction
E11 – LBD Tributary to Center Creek at Carl Junction
E12 – LBD Tributary to Center Creek 1 mile below Klondike mines
E13 – Center Creek near Smithfield, 10 miles below Oronogo

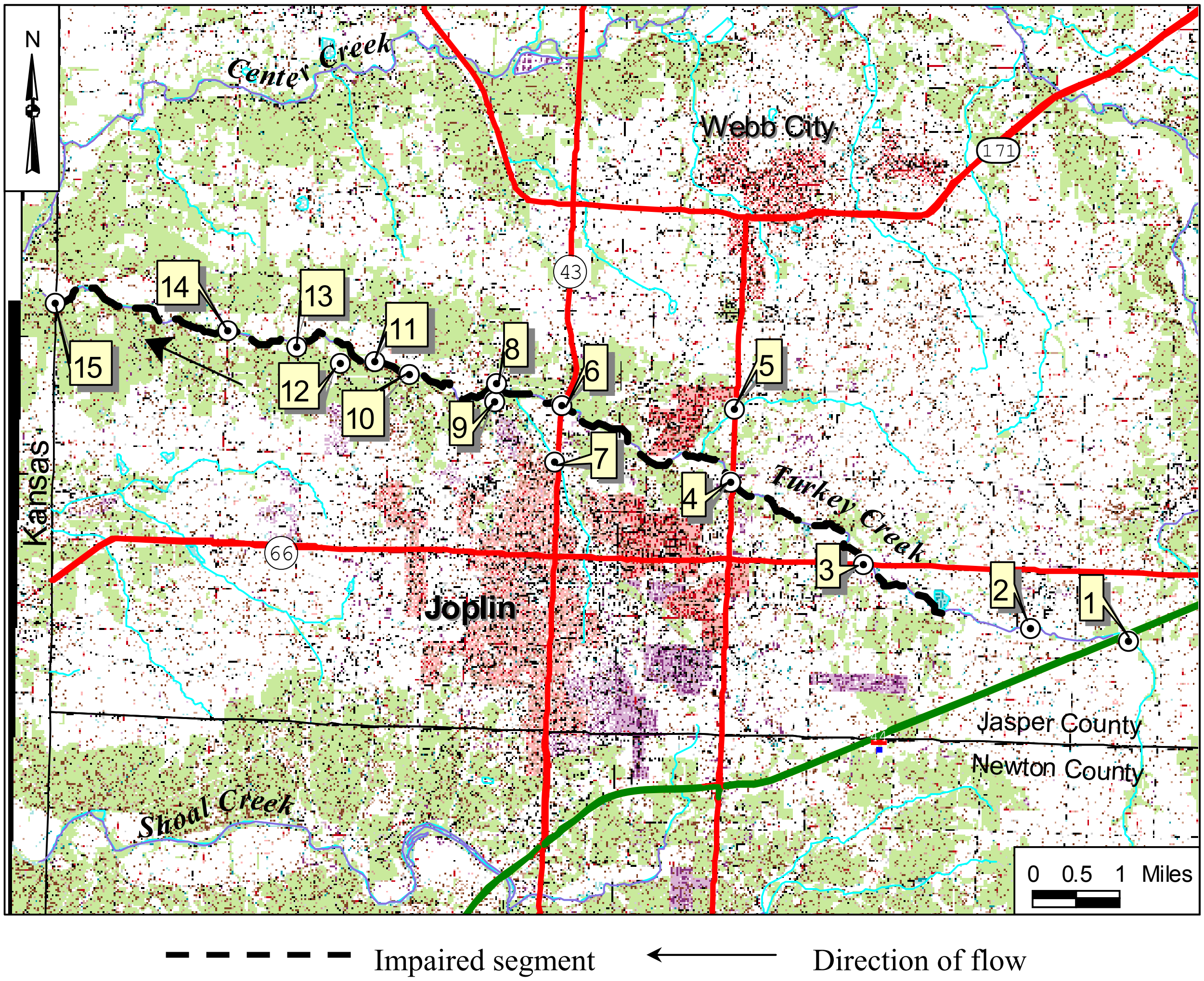
Continued next page.

Index to Sites (cont.)

USGS
G1 – Center Creek at Hwy Alt. 71 near Fidelity
G2 – Center Creek 2.5 miles below Fidelity
G3 – Center Creek 0.1 mile above Grove Creek
G4 – Center Creek 0.1 mile below Grove Creek
G5 – Center Creek at Hwy HH 1.5 miles below Grove Creek
G6 – Center Creek 0.1 mile below Stout's Branch
G7 – Center Creek 0.1 mile above Mineral Branch
G8 – Mineral Branch 2 miles above mouth
G9 – Center Creek 0.1 mile below Mineral Branch
G10 – Center Creek 0.1 mile below Oronogo Branch
G11 – Center Creek 1.5 miles below Oronogo Branch
G12 – Center Creek 4.5 miles below Oronogo Branch
G13 – Center Creek at Carl Junction 8 miles below Oronogo Branch
G14 – Center Creek near Smithfield, 10 miles below Oronogo Branch

Kansas Department of Health and Environment
KDHE – Center Creek near Smithfield

Appendix B-2.
Turkey Creek topographic map with impaired segment and sampling sites

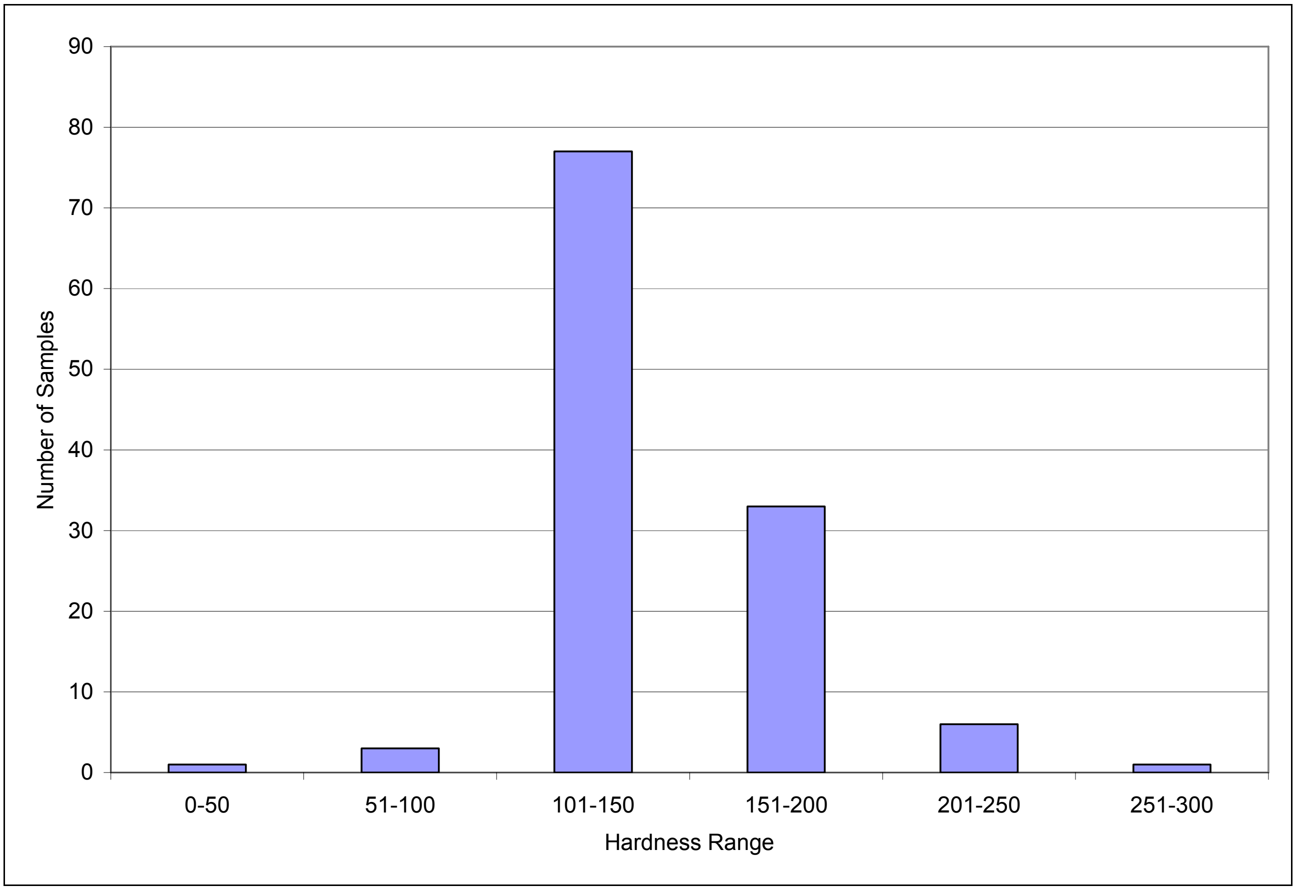


Sample Site Index

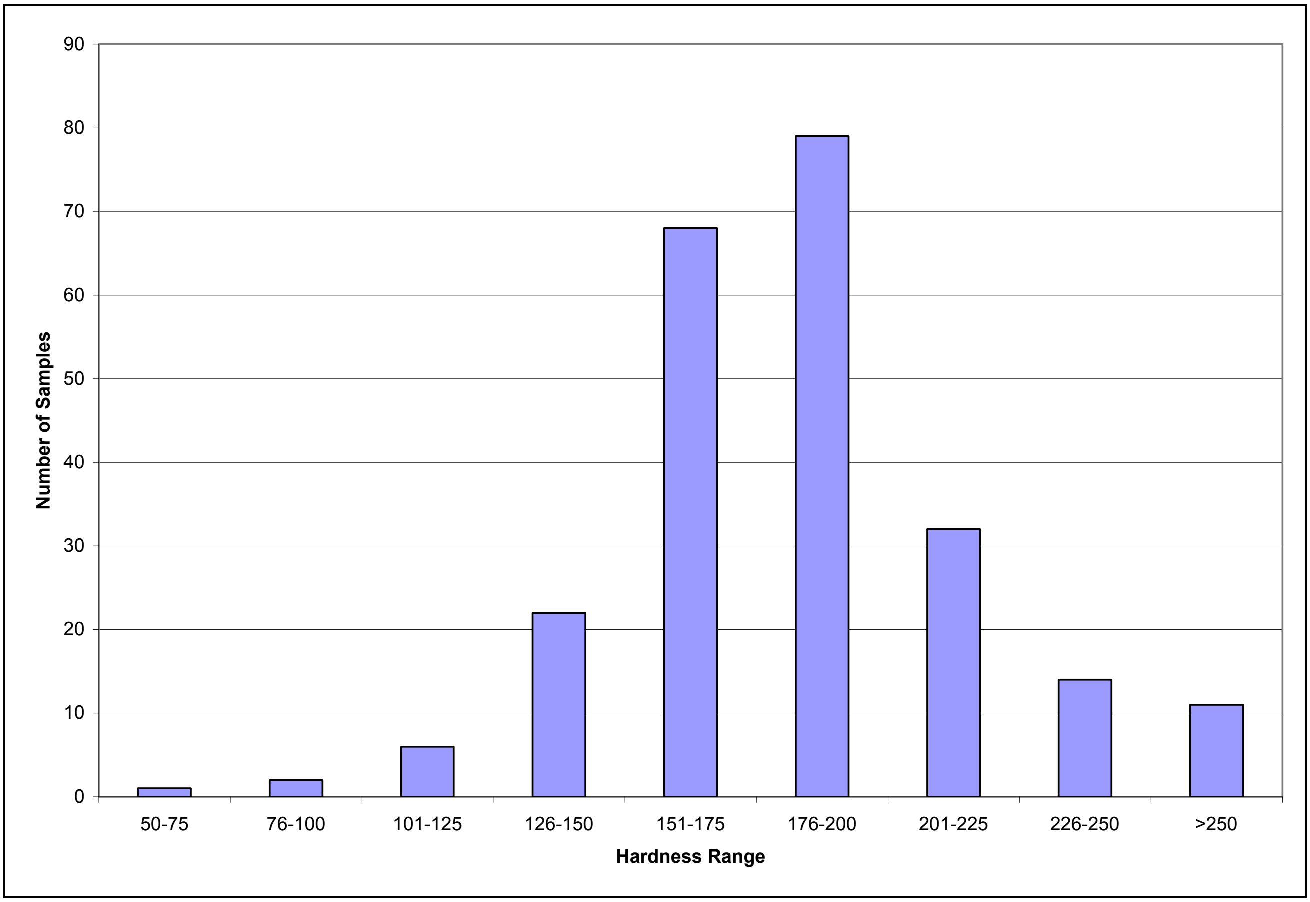
1 – Turkey Creek 1.2 miles above Duenweg
2 – Turkey Creek at Duenweg
3 – Turkey Creek 2.4 miles below Duenweg
4 – Turkey Creek 4.5 miles below Duenweg
5 – Tributary to Turkey Creek from Oakland Park
6 – Turkey Creek 0.6 miles above Joplin Creek
7 – Joplin Creek near mouth
8 – Turkey Creek below Joplin Creek and above Lone Elm Hollow
9 – Lone Elm Hollow near mouth
10 – Turkey Creek below Leadville Hollow and above Joplin Turkey Creek WWTP
11 – Joplin Turkey Creek WWTP
12 – Chitwood Hollow near mouth
13 – Turkey Creek 1 mile below Joplin Turkey Creek WWTP
14 – Turkey Creek at Highway P, 3.6 miles below Lone Elm Hollow
15 – Turkey Creek 4.9 miles below Joplin Turkey Creek WWTP

Appendix C. Stream Hardness Frequency Distribution Graphs

C-1: Stream Hardness Frequency Distribution near Carterville, Missouri (USGS 07186400)



Appendix C. continued
C-2: Hardness Distribution in Center Creek near Smithfield, Missouri (USGS 07186480)



Appendix D: Data for Center and Turkey Creeks

D-1: Data used in the calculations for the Carterville subwatershed (USGS 07186400 at Hwy HH, 1.5 miles below Grove Creek, Site E2/G5)

Org	Year	Mo	Day	Time	Flow	Hard	DZN	TZN
USGS	1966	10	26		35	14	210	
USGS	1966	11	16		38	9	200	
USGS	1966	12	13		28	2	380	
USGS	1967	1	11		42	3	20	
USGS	1967	2	15		58	10	440	
USGS	1967	3	14		45	13	420	
USGS	1967	4	11		62	18	550	
USGS	1967	5	17		250	16	460	
USGS	1967	6	13		111	24	200	
USGS	1967	7	12		254	20	160	
USGS	1967	9	13		38	20	480	
USGS	1967	10	11	1645	63	12	150	
USGS	1967	11	15	900	181	10	60	
USGS	1967	12	19	1315	298	9	50	
USGS	1968	1	17	915	104	4	60	
USGS	1968	2	13	1645	320	7	30	
USGS	1968	3	20	815	2300	9	40	
USGS	1968	5	15	1145	126	21	220	
USGS	1968	6	26	1500	650	18	50	
USGS	1968	7	18		121	23		
USGS	1968	8	15	1835	88	24	50	
USGS	1968	9	25	1540	69	20	30	
USGS	1968	10	23	1415	95	11	40	
USGS	1968	11	13	1700	241	10	30	
USGS	1968	12	5	830	352	9	60	
USGS	1969	1	7	1700	277	8	40	
USGS	1969	2	5	1720	359	9	50	
USGS	1969	3	4	820	183	8	50	
USGS	1969	4	21	1200	200	16	20	
USGS	1969	5	14	1640	125	20	30	
USGS	1969	6	9	1700	83	21	20	
USGS	1969	7	7	1630	78	29	410	
USGS	1969	8	14	930	38	24	20	
USGS	1969	9	3	1300	53	23	30	
USGS	1969	10	7	1540	35	18	40	
USGS	1969	11	4	1400	72	9	30	
USGS	1969	12	2	1530	43	7	54	
USGS	1970	1	5	1330	56	0	80	
USGS	1970	2	10	910	60	4	49	
USGS	1970	3	3	1020	56	13	80	
USGS	1970	4	7	1515	210	16	41	
USGS	1970	5	6	1800	435	20	51	
USGS	1970	6	9	1446	111	22	64	
USGS	1970	7	8	1210	70	26	73	

Org	Year	Mo	Day	Time	Flow	Hard	DZN	TZN
USGS	1970	8	11	1430	27	26	150	
USGS	1970	9	3	1330	43	24	250	
USGS	1970	10	6	1520	137	19	160	
USGS	1970	11	4	1230	281	10	220	
USGS	1970	12	1	1545	147	15	240	
USGS	1971	1	5	1315	402	4	130	
USGS	1971	2	2	1415	78	4	360	
USGS	1971	3	2	1315	178	8	260	
USGS	1971	4	7	1510	87	13	62	
USGS	1971	5	5	1345	80	20	60	
USGS	1971	6	3	1620	62	23	100	
USGS	1971	7	14	1500	29	30	120	
USGS	1971	8	10	1440	46	26	160	
USGS	1971	8	31	1445	25	24	310	
USGS	1971	10	5	1445	43	20	390	
USGS	1971	11	2	1700	39	16	495	
USGS	1971	12	1	1600	39	6	540	
USGS	1972	1	5	845	133	1	62	
USGS	1972	2	2	1500	63	4	480	
USGS	1972	3	14	1330	46	14	460	
USGS	1972	4	11	1300	40	18	500	
USGS	1972	5	2	1400	242	17	170	
USGS	1972	6	8	1110	38	25	510	
USGS	1972	7	12	1245	25	24	500	
USGS	1972	8	16	1500	18	28	760	
USGS	1972	9	7	930	30	22		
USGS	1972	10	3	1610	90	18	190	
USGS	1972	11	15	1430	881	10	0.01	
USGS	1972	12	15	1350	232	5	280	
USGS	1973	1	16	1510	180	10	240	
USGS	1973	2	14	830	279	8	120	
USGS	1973	3	14	1515	1020	15	90	
USGS	1973	4	10	1210	480	8	300	
USGS	1973	5	15	1500	368	16	130	
USGS	1973	6	11	1630	272	22	80	
USGS	1973	7	11	1610	137	25	90	
USGS	1973	8	9	1215	74	24	70	
USGS	1973	9	5	1500	971	21	50	
USGS	1973	10	5	930	173	17	70	
USGS	1973	12	6	1100	1380	9	60	
USGS	1974	1	7	1650	315	6	50	
USGS	1974	2	4	1300	290	8	20	
USGS	1974	3	18	1330	860	13	50	
USGS	1974	4	16	1550	246	15	40	
USGS	1974	5	14	1330	154	20	30	
USGS	1974	6	10	1330	1000	18	20	
USGS	1974	7	8	1220	135	26	20	
USGS	1974	8	7	1420	135	23	30	
USGS	1974	9	4	1410	140	18	20	
USGS	1974	10	2	1220	69	15	30	

Org	Year	Mo	Day	Time	Flow	Hard	DZN	TZN
USGS	1974	11	11	1315	641	13	40	
USGS	1974	12	9	1220	338	6	20	
USGS	1975	1	6	1240	234	8	20	
USGS	1975	2	3	1230	750	10	30	
USGS	1975	3	5	900	669	8	20	
USGS	1975	4	4	915	610	8	30	
USGS	1975	5	13	1420	192	17	20	
USGS	1975	6	10	1230	204	21	50	
USGS	1975	7	7	1530	103	28	0.01	
USGS	1976	9	21		52		30	40
USGS	1979	9	12	1130	74	21	140	
USGS	1979	10	3	1000	41	18	34	30
USGS	1979	11	14	930	36	6	200	210
USGS	1980	1	9	945	45	2	53	81
USGS	1980	4	16	945	257	12	19	321
USGS	1980	7	1	1155	52	28	18	35
USGS	1980	10	15	815	16	18	480	610
USGS	1981	1	14	1600	27	2	210	300
USGS	1981	4	15	1230	35	18	130	172
USGS	1981	7	14	1130	62	28	58	
USGS	1981	10	21	915	90	14	130	320
USGS	1982	1	20	1045	57	4	320	93
USGS	1982	4	14	1015	119	18	250	140
USGS	1982	7	7	1030	147	24	10	20
USGS	1982	10	7	1130	55	19	10	20
USGS	1983	1	12	1130	164	6	20	20
USGS	1983	4	6	1215	980	10	27	40
USGS	1983	7	6	1500	308	22	22	50
USGS	1983	10	19	1230	42	16	29	20
USGS	1984	1	5	1300	114	6	23	30
USGS	1984	4	4	1500	683	10	19	40
USGS	1984	7	12	1525	74	27	12	40
USGS	1984	10	4	1600	31	18	26	80
USGS	1985	1	10	815	430	7	30	40
USGS	1985	4	17	1230	345	17	53	50
USGS	1985	7	10	1300	154	23	33	50
USGS	1985	10	10	1100	41	17	30	30
USGS	1986	1	9	1115	213	4	11	20
USGS	1986	4	9	1250	711	14	11	30
USGS	1986	7	9	1030	71	26	22	20
USGS	1986	10	15	1730	256	14	21	160
USGS	1987	1	7	1210	91	6	12	20
USGS	1987	4	8	1635	227	16	6	20
USGS	1987	7	8	800	84	24	9	20
USGS	1987	10	6	1530	30	14	24	40
USGS	1988	1	11	1500	276	5	9	20
USGS	1988	4	6	1330	532	15	9	60
USGS	1988	7	13	800	57	24	7	10
USGS	1988	10	5	915	50	14	11	20
USGS	1989	1	4	1600	370	10	12	20

USGS	1989	4	4	1345	342	14	4	10
USEPA	1993	5	9				5	
USEPA	1993	9	8				2.499	

Abbreviations and notes:
Org = Organization that collected the data.
USGS = United States Geologic Survey.
USEPA = United States Environmental Protection Agency
MDNR = Missouri Department of Natural Resources

Flow = instream flow in cubic feet per second (ft^3/s)
Hard = water hardness as $CaCO_3$ in mg/L
DZN = dissolved zinc in μg/L
TZN = total zinc in μg/L

D-2: Data used in the calculations for the Smithfield subwatershed (USGS 07186480, Center Creek near Smithfield, Site E13/G14)

Org	Year	Month	Day	Time	Flow	Hard	DZN	TZN
USGS	1963	12	18		23		920	
USGS	1964	3	30		33		900	
USGS	1964	6	8		90		65	
USGS	1964	12	1		45		100	
USGS	1966	7	27		40		300	
USGS	1966	8	25		56		100	
USGS	1967	4	16	1530	168		0.01	
USGS	1968	4	16		168	144		
USGS	1968	12	5	1700	613	172		
USGS	1969	2	4	1430	721	161		
USGS	1969	4	24	830	263	190	690	
USGS	1969	6	10	1000	98	227	460	
USGS	1969	8	14	1400	45	227	520	
USGS	1969	10	7	1030	47		860	
USGS	1969	12	2	1100	60		862	
USGS	1970	2	10	1420	76		720	
USGS	1970	4	7	1015	274		520	
USGS	1970	6	9	1010	168		240	
USGS	1970	8	11	1020	40		330	
USGS	1970	10	6	1030	185	195	590	
USGS	1970	12	3	1200	172	200	780	
USGS	1971	2	2	1020	134	200	720	
USGS	1971	4	6	1340	135	190	385	
USGS	1971	6	2	1030	82	270	1000	
USGS	1971	8	10	1100	61	240	580	
USGS	1971	10	5	1120	63	300	1900	
USGS	1971	11	30	1410	90	300	1470	
USGS	1972	2	2	1100	75	240	1100	
USGS	1972	4	11	1600	56	260	780	
USGS	1972	6	8	1000	52	230	770	
USGS	1972	8	15	1105	25	300	1070	

Org	Year	Month	Day	Time	Flow	Hard	DZN	TZN
USGS	1972	10	2	1640	107	220	1700	
USGS	1972	12	15	1635	355	170	840	
USGS	1973	2	15	1345	415	160	710	
USGS	1973	4	10	1620	940	140	650	
USGS	1973	6	13	830	730	160	400	
USGS	1973	8	9	1000	77	190	410	
USGS	1973	10	4	1300	560	160	630	
USGS	1973	12	3	1530	662	170	460	
USGS	1974	2	4	1640	350	180	480	
USGS	1974	4	17	1430	252	170	360	
KDHE	1974	6	4	1200				540
USGS	1974	6	10	1635	1240	120	350	
USGS	1974	8	5	1400	92	180	170	
KDHE	1974	8	20	1300				1100
USGS	1974	10	2	920	95	200	610	
KDHE	1974	10	22	1205				630
KDHE	1974	12	3	1205				600
USGS	1974	12	9	1510	450	150	500	
USGS	1975	2	3	1515	1200	140	490	
KDHE	1975	2	25	1200				820
KDHE	1975	4	1	1205				640
USGS	1975	4	3	900	892	160	500	
USGS	1975	6	10	1510	294	170	340	
KDHE	1975	6	17	1150				2520
KDHE	1975	12	3	955				740
USGS	1976	3	10		560	160	700	800
KDHE	1976	6	2	850				550
USGS	1976	9	21	1315	46		30	
USGS	1976	9	22		58		360	400
KDHE	1976	11	9	840				880
KDHE	1977	6	1	935				800
KDHE	1977	6	1	935	46		800	
USGS	1977	7	20	820	160		250	340
USGS	1977	8	17	850	89		600	1000
USGS	1977	9	21	1625	142		30	1000
USGS	1977	10	12	1015	191		900	1400
KDHE	1977	11	2	915				920
USGS	1977	11	18	930	122		90	340
USGS	1977	12	13	1115	224		100	100
USGS	1977	12	20	850	107		30	
USGS	1978	1	25	1010	90		220	220
USGS	1978	2	8	1515	50		20	
USGS	1978	2	22	1415	125		110	220
USGS	1978	3	14	1645	345		300	1100
USGS	1978	4	5	830	960		550	550
USGS	1978	5	3	900	293		700	
USGS	1978	5	16	1500	213		20	
USGS	1978	5	23	1130	1000		30	
USGS	1978	5	23	1720	1670		20	
USGS	1978	5	24	900	1060		60	

Org	Year	Month	Day	Time	Flow	Hard	DZN	TZN
USGS	1978	6	1	1810	282		40	
KDHE	1978	6	6	909				590
USGS	1978	6	7	800	105		550	
USGS	1978	7	12	830	87		500	600
USGS	1978	7	12	1030	79		30	
USGS	1978	8	1	1645	78		7	50
USGS	1978	9	5	1730	59		40	110
USGS	1978	10	11	1500	48	150	250	400
USGS	1979	1	9	1530	66	210	550	900
USGS	1979	1	10	915	40		50	
USGS	1979	2	14	930	161		140	
KDHE	1979	2	14	930				550
USGS	1979	3	7	845	370		50	
USGS	1979	4	4	830	300	160	40	100
USGS	1979	4	4	915	224		60	
USGS	1979	5	9	1445	216		40	
USGS	1979	6	6	1000	165		30	
USGS	1979	7	24	1500	125	180	143	331
USGS	1979	7	24	1545	72		40	
USGS	1979	8	15	930	81		30	
USGS	1979	10	3	840	50	200	380	388
USGS	1980	1	8	1630	65	220	642	
KDHE	1980	4	9	852				500
USGS	1980	4	15	1550	300	160	277	500
USGS	1980	7	1	1030	65	190	128	297
USGS	1980	10	15	1000	27	270	620	880
USGS	1981	1	14	1530	50	200	220	700
KDHE	1981	4	8	847		232		410
USGS	1981	4	15	1345	62	230	20	550
KDHE	1981	5	6	842		211		
KDHE	1981	6	3	845		231		
KDHE	1981	7	8	843		214		
USGS	1981	7	14	1100	75	200	150	310
KDHE	1981	8	5	845		258		
KDHE	1981	9	9	835		263		
KDHE	1981	10	7	910		297		
USGS	1981	10	21	1230	110	220	750	1300
KDHE	1981	11	4	837		211		
KDHE	1981	12	2	943		221		
KDHE	1982	1	6	901		204		
USGS	1982	1	20	1200	80	210	490	1000
KDHE	1982	3	3	910		186		
KDHE	1982	4	7	852		194		430
USGS	1982	4	14	1105	150	180	280	340
KDHE	1982	5	5	855		197		
KDHE	1982	6	9	900		177		
KDHE	1982	7	7	820		192		
USGS	1982	7	7	1130	130	170	140	380
KDHE	1982	8	11	908		192		
KDHE	1982	9	8	951		184		

Org	Year	Month	Day	Time	Flow	Hard	DZN	TZN
KDHE	1982	10	6	906		214		
USGS	1982	10	7	1230	60	200	200	290
KDHE	1982	11	3	940		254		
KDHE	1982	11	30	1157		172		
KDHE	1983	1	5	920		194		
USGS	1983	1	12	1300	150	170	350	430
KDHE	1983	2	8	1155		182		
KDHE	1983	3	8	1125		197		
KDHE	1983	4	5	1228		118		860
USGS	1983	4	6	1300	1380	140	450	610
KDHE	1983	5	10	1201		157		
KDHE	1983	6	7	1145		177		
KDHE	1983	7	5	1230		93		
USGS	1983	7	6	1350	600	140	420	640
KDHE	1983	8	2	1220		192		
KDHE	1983	9	6	1151		192		
KDHE	1983	10	4	1227		213		
USGS	1983	10	19	1345	68	220	350	480
KDHE	1983	11	8	1230		202		
KDHE	1983	12	6	1239		167		
USGS	1984	1	5	1400	285		560	670
KDHE	1984	1	10	1217		147		
KDHE	1984	2	7	1220		182		
KDHE	1984	3	13	1258		167		
USGS	1984	4	4	1600	960	130	330	490
KDHE	1984	4	10	1248		140		
KDHE	1984	5	8	1313		170		420
KDHE	1984	6	5	1208		180		
KDHE	1984	7	10	1350		184		
USGS	1984	7	12	1715	82	180	130	190
KDHE	1984	8	7	1315		194		
KDHE	1984	9	4	1204		214		
USGS	1984	10	4	1700	30	220	180	280
KDHE	1984	10	9	1206		226		
KDHE	1984	11	6	1350		169		
KDHE	1984	12	4	1347		178		
KDHE	1985	1	8	1441		157		
USGS	1985	1	9	1230	615	160	410	490
KDHE	1985	2	12	1226		176		
KDHE	1985	3	12	1320		154		
KDHE	1985	4	2	1310		134		
USGS	1985	4	17	1400	580	160	360	350
KDHE	1985	5	7	1240		168		
KDHE	1985	6	4	1337		166		450
KDHE	1985	7	9	1305		179		
USGS	1985	7	10	1100	230	170	170	330
KDHE	1985	8	6	1240		186		
KDHE	1985	9	3	1325		203		
KDHE	1985	10	8	1355		219		
USGS	1985	10	10	1300	96	210	8	470

Org	Year	Month	Day	Time	Flow	Hard	DZN	TZN
KDHE	1985	11	5	1310		216		
KDHE	1985	12	3	1347		143		
KDHE	1986	1	7	1335		167		
USGS	1986	1	9	1315	245	170	320	390
KDHE	1986	2	4	1315		170		
KDHE	1986	3	4	1200		196		
KDHE	1986	4	8	1225		68		1290
USGS	1986	4	9	1330	1100	110	220	560
KDHE	1986	5	6	1143		187		
KDHE	1986	6	3	1338		192		
KDHE	1986	7	8	1138		193		
USGS	1986	7	9	815	91	190	150	250
KDHE	1986	8	5	1152		177		
KDHE	1986	9	9	1153		210		
USGS	1986	10	16	800	300	180	420	550
KDHE	1986	10	21	1320		184		
KDHE	1986	11	4	1235		202		
KDHE	1986	12	9	1158		199		
USGS	1987	1	7	1330	155	190	390	430
KDHE	1987	1	13	1220		196		
KDHE	1987	2	2	1247		184		
KDHE	1987	3	10	1213		184		
USGS	1987	4	8	1500	300	170	210	290
KDHE	1987	4	14	1330		188		
KDHE	1987	5	12	1155		196		
KDHE	1987	6	9	1225		204		560
USGS	1987	7	8	930	30	200	270	480
KDHE	1987	7	14	1211		217		
KDHE	1987	8	11	1145		188		
KDHE	1987	9	8	1221		221		
USGS	1987	10	6	1300	50	230	280	449
KDHE	1987	10	13	1206		233		
KDHE	1987	11	3	1203		262		
KDHE	1987	12	8	1237		184		
USGS	1988	1	11	1630	385	160	340	390
KDHE	1988	1	12	1202		167		
KDHE	1988	2	9	1146		174		
KDHE	1988	3	8	1215		154		
USGS	1988	4	6	1445	840	140	230	430
KDHE	1988	4	12	1155		155		
KDHE	1988	5	17	1215		172		330
KDHE	1988	6	14	1248		190		
KDHE	1988	7	12	1157		189		
USGS	1988	7	13	1030	100	190	160	
KDHE	1988	8	9	1202		173		
KDHE	1988	9	13	1228		202		
USGS	1988	10	6	1030	140	230	740	780
KDHE	1988	10	11	1143		236		
KDHE	1988	11	7	1205		223		
KDHE	1988	12	6	1200		182		

Org	Year	Month	Day	Time	Flow	Hard	DZN	TZN
USGS	1989	1	5	815	460	160	450	520
KDHE	1989	1	10	1150		176		
KDHE	1989	3	14	1150		141		
KDHE	1989	4	4	1200		155		
USGS	1989	4	4	1500	450	160	240	330
KDHE	1989	5	9	1200		179		
KDHE	1989	6	13	1205		202		440
KDHE	1989	7	11	1255		189		
KDHE	1989	8	15	1255		190		
KDHE	1989	9	12	1200		193		
KDHE	1989	10	10	1245		206		
KDHE	1989	10	31	1205		211		
KDHE	1990	4	10	1220		125		1220
KDHE	1990	6	12	1155		158		485
KDHE	1990	8	14	1340		175		301
KDHE	1990	10	9	1015		230		1437
KDHE	1990	12	4	1105		181		575
USGS	1993	4	27	1630	406	170	270	
USEPA	1993	5	10			173	147	
USGS	1993	5	18	1730	3550	87		
USGS	1993	6	22	930	838	120	160	
USGS	1993	7	12	1400	680	140		
USGS	1993	8	23	1400	178	160	110	
USEPA	1993	9	8			182	7	
USGS	1993	9	15	1540	771	110		
USGS	1993	10	6	1330	482	150	200	
USGS	1993	11	16	1400	355	130		
USGS	1993	12	7	1400	267	160	240	
USGS	1994	1	5	1400	150	170		
USGS	1994	2	11	900	177	170	270	
USGS	1994	3	8	1330	372	160		
USGS	1994	4	6	1400	360	170	250	
USGS	1994	5	23	1730	287	170	130	
USGS	1994	6	16	1500	227	150	100	
USGS	1994	7	13	1530	103	160		
USGS	1994	8	17	1700	50	160	67	
USGS	1994	9				164		
USGS	1994	9	19	1305	56	180	160	
USGS	1994	10	5	1530	55	190		
USGS	1994	11	2	1500	158	180		
USGS	1994	12	8	930	295	170	260	
USGS	1995	1	11	1600	137	170		
USGS	1995	2	7	1500	360	160	210	
USGS	1995	3	2	1030	179	180		
USGS	1995	4	4	1600	156	160	130	
USGS	1995	5	22	1500	393	160	200	
USGS	1995	6	22	1100	428	150	150	
USGS	1995	7	14	1000	220	160		
USGS	1995	8	18	1000	108	170	110	
USGS	1999	11	2	840	48	190	244	242

USGS	2000	5	23	815	186	170	93	361
USGS	2000	7	25	1400	158	180	161	228
MDNR	2000	10	11			210	208	240
USGS	2000	11	28	1245	49	210	327	318
USGS	2001	5	22	1415	137	180	126	363
USGS	2001	11	28	900	79	200	169	371
KDHE	2002	2	5	1646		152		351
KDHE	2002	4	2	1605		168		295
USGS	2002	5	22	1010	973	150	196	387
KDHE	2002	6	4	1603		154		271
USGS	2002	7	23	1600	349	150	270	700
KDHE	2002	8	6	1721		169		161
KDHE	2002	10	8	1639		176		149
USGS	2002	11	5	1555	51	190	190	188
KDHE	2002	12	3	1642		193		258
USGS	2003	5	13	1015	248	140	118	365
USGS	2003	7	8	1045	108	190	159	306

Additional abbreviations:
KDHE = Kansas Department of Health and Environment
MDNR = Missouri Department of Natural Resources

D-3: Data used in the calculations for the Turkey Creek watershed

(Map in Appendix B-2)

Site #	Site Name	Org	Date	Flow	Hard	TZN	DZN
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	6/4/1974	17		510	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	8/20/1974	65		210	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	10/2/1974	16			140
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	10/22/1974	21		360	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	11/11/1974	62			660
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	12/3/1974	32		510	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	12/9/1974	105			550
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	1/6/1975	53			550
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	2/3/1975	62			700
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	2/25/1975	19		980	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	3/4/1975	44			780
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	4/1/1975	57		1000	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	4/3/1975	62			880
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	5/14/1975	30			180
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	6/10/1975	64			280
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	6/17/1975	73		1040	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	7/7/1975	3			60
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	12/3/1975	12		430	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	3/10/1976	40	190	620	500
2	Turkey Cr. @ Duenweg	USGS	3/10/1976	5.8	46	300	240
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	6/2/1976	44		430	
8	Turkey Cr. bl. Joplin Cr.& ab. Lone Elm Hol.	USGS	9/23/1976	5		480	280
7	Joplin Cr. nr. Mouth	USGS	9/23/1976	4.9		800	180

9	Lone Elm Hollow nr. Mouth	USGS	9/23/1976	1.4		730	670
3	Turkey Cr. 2.4 mi.bl. Duenweg	USGS	9/23/1976	3		240	170
2	Turkey Cr. @ Duenweg	USGS	9/23/1976	0.02		330	288
4	Turkey Cr. 4.5 mi.bl. Duenweg	USGS	9/23/1976	3.1		200	190
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	9/24/1976	13		240	60
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	11/9/1976	47		330	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	6/1/1977	76		0	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	11/2/1977	116		1600	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	6/6/1978	59		590	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	3/14/1979	28		610	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	4/9/1980	86		670	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	9/9/1981	35		250	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	4/7/1982			330	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	4/5/1983	124		2000	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	5/8/1984	35		430	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	6/4/1985	19		410	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	4/8/1986			980	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	6/9/1987			270	
9	Lone Elm Hollow nr. Mouth	MDNR	8/17/1988			330	130
	Leadville Hollow nr. Mouth	MDNR	8/17/1988			1300	950
6	Turkey Cr. 0.6 mi.ab. Joplin Cr.	MDNR	8/17/1988			130	92
10	Turkey Cr. bl.Leadville Hol.&ab.TC WWTP	MDNR	8/17/1988			550	430
15	Turkey Cr. 4.9 mi.bl. TC-WWTP	MDNR	8/17/1988			230	140
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	MDNR	8/17/1988			210	140
7	Joplin Cr. nr. Mouth	MDNR	8/17/1988			150	46
Between 12 &13	Turkey Cr.0.8 mi.bl. Joplin TC WWTP	MDNR	8/17/1988			230	140
8	Turkey Cr. bl. Joplin Cr.& ab. Lone Elm Hol.	MDNR	8/17/1988			110	68
4	Turkey Cr. 4.5mi.bl. Duenweg	MDNR	8/17/1988			120	75
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	MDNR	8/18/1988			190	150
9	Lone Elm Hollow nr. Mouth	MDNR	8/18/1988			390	170
7	Joplin Cr. nr. Mouth	MDNR	8/18/1988			100	38
	Leadville Hollow nr. Mouth	MDNR	8/18/1988			1500	1000
6	Turkey Cr. 0.6 mi.ab. Joplin Cr.	MDNR	8/18/1988			120	93
10	Turkey Cr. bl.Leadville Hol.&ab.TC WWTP	MDNR	8/18/1988			400	320
15	Turkey Cr. 4.9 mi.bl. TC-WWTP	MDNR	8/18/1988			240	180
Between 12 &13	Turkey Cr.0.8 mi.bl. Joplin TC WWTP	MDNR	8/18/1988			200	130
8	Turkey Cr. bl. Joplin Cr.& ab. Lone Elm Hol.	MDNR	8/18/1988			110	79
4	Turkey Cr. 4.5mi.bl. Duenweg	MDNR	8/18/1988			130	99
9	Lone Elm Hollow nr. Mouth	MDNR	9/28/1988			950	710
	Leadville Hollow nr. Mouth	MDNR	9/28/1988			1600	1600
	Possum Hollow nr. Mouth	MDNR	9/28/1988			1600	1700
6	Turkey Cr. 0.6 mi.ab. Joplin Cr.	MDNR	9/28/1988			190	170
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	MDNR	9/28/1988			450	360
10	Turkey Cr. bl.Leadville Hol.&ab.TC WWTP	MDNR	9/28/1988			490	460
15	Turkey Cr. 4.9 mi.bl. TC-WWTP	MDNR	9/28/1988			500	420
8	Turkey Cr. bl. Joplin Cr.& ab. Lone Elm Hol.	MDNR	9/28/1988			370	300
7	Joplin Cr. nr. Mouth	MDNR	9/28/1988			500	290

Between 12 &13	Turkey Cr.0.8 mi.bl. Joplin TC WWTP	MDNR	9/28/1988	8.6		470	360
12	Chitwood Hollow nr. Mouth	MDNR	9/28/1988			510	480
4	Turkey Cr. 4.5mi.bl. Duenweg	MDNR	9/28/1988			210	170
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	6/13/1989			310	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	4/10/1990			690	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	6/12/1990			689	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	8/14/1990			370	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	10/9/1990			571	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	12/4/1990			492	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	2/8/1993			554	
1	Turkey Cr. 1.2 mi.ab. Duenweg	USEPA	5/9/1993		33		20
7	Joplin Cr. nr. Mouth	USEPA	5/10/1993		197		199
Between 12 &13	Turkey Cr.0.8 mi.bl. Joplin TC WWTP	USEPA	5/10/1993		162		196
8	Turkey Cr. bl. Joplin Cr.& ab. Lone Elm Hol.	USEPA	5/10/1993		124		307
9	Lone Elm Hollow nr. Mouth	USEPA	5/10/1993		400		1850
	Leadville Hollow nr. Mouth	USEPA	5/10/1993		328		1110
4	Turkey Cr. 4.5mi.bl. Duenweg	USEPA	5/10/1993		98		355
5	Trib. Turkey Cr. from Oakland Park	USEPA	5/10/1993		84		1250
12	Chitwood Hollow nr. Mouth	USEPA	5/13/1993		356		
	RBD Trib. Turkey Cr. 0.2 mi.ab. TC WWTP	USEPA	5/13/1993		223		
7	Joplin Cr. nr. Mouth	USEPA	9/8/1993		202		13
9	Lone Elm Hollow nr. Mouth	USEPA	9/8/1993		561		755
8	Turkey Cr. bl. Joplin Cr.& ab. Lone Elm Hol.	USEPA	9/8/1993		197		7
4	Turkey Cr. 4.5mi.bl. Duenweg	USEPA	9/8/1993		214		5
12	Chitwood Hollow nr. Mouth	USEPA	9/9/1993		420		490
Between 12 &13	Turkey Cr.0.8 mi.bl. Joplin TC WWTP	USEPA	9/9/1993		221		41
	Leadville Hollow nr. Mouth	USEPA	9/9/1993		462		694
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	6/14/1994			371	
8	Turkey Cr. bl. Joplin Cr.& ab. Lone Elm Hol.	AATA	7/13/1994	78.1	109	259	241
8	Turkey Cr. bl. Joplin Cr.& ab. Lone Elm Hol.	AATA	7/18/1994	253	114	665	627
8	Turkey Cr. bl. Joplin Cr.& ab. Lone Elm Hol.	AATA	7/26/1994	6.9	300	290	258
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	8/9/1994			366	
	Turkey Cr. nr. Mouth	USGS	8/31/1994		224		
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	10/11/1994			471	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	12/6/1994			598	

14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	11/2/1999	13	220	355	408
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	5/23/2000	52	220	481	336
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	7/26/2000	26	220	356	236
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	11/29/2000	15	245	354	377
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	5/23/2001	26	228	356	275
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	11/27/2001	23	260	330	200
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	2/5/2002		214.834	633	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	4/2/2002		227.727	425	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	5/21/2002	116	210	617	457
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	6/4/2002		218.263	378	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	7/24/2002	42	210	384	383
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	8/6/2002		226.205	306	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	10/8/2002		223.864	334	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	11/6/2002	17	230	346	413
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	KDHE	12/3/2002		242.903	414	
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	5/13/2003	25	220	409	382
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	7/8/2003	27	250	317	320
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	11/4/2003	14	260	324	304
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	5/11/2004	45	230	481	488
14	Turkey Cr.@Hwy P, 3.6mi.bl. Lone Elm Hol.	USGS	7/20/2004	42	230	258	255

Abbreviations and notes:

Org = Organization that collected the data
KDHE = Kansas Department of Health and Environment
USGS = United States Geologic Survey
MDNR = Missouri Department of Natural Resources
AATA = laboratory for Eagle Pitcher

mi. = miles
bl. = below (downstream of)
ab. = above (upstream of)
@ = at
nr. = near
Hwy = Highway
Hol. = Hollow
TC = Turkey Creek
WWTP = Wastewater Treatment Plant

Flow = instream flow in cubic feet per second (ft^3/s)
Hard = water hardness as $CaCO_3$ in mg/L
TZN = total recoverable zinc in ug/L
DZN = dissolved zinc in ug/L